US009201694B2

(12) **United States Patent**
Shimamura

(10) **Patent No.: US 9,201,694 B2**
(45) **Date of Patent: Dec. 1, 2015**

(54) **JOB MANAGEMENT APPARATUS AND JOB MANAGEMENT METHOD**

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(73) Assignee: **FUJITSU LIMITED**, Kawasaki (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 299 days.

(21) Appl. No.: **13/760,119**

(22) Filed: **Feb. 6, 2013**

(65) **Prior Publication Data**

US 2013/0152089 A1 Jun. 13, 2013

Related U.S. Application Data

(63) Continuation of application No. PCT/JP2010/063534, filed on Aug. 10, 2010.

(51) **Int. Cl.**

G06F 9/46	(2006.01)
G06F 9/50	(2006.01)
G06F 15/173	(2006.01)

(52) **U.S. Cl.**

CPC ***G06F 9/50*** (2013.01); ***G06F 9/5005*** (2013.01); ***G06F 9/5027*** (2013.01); ***G06F 9/5066*** (2013.01); ***G06F 15/17381*** (2013.01)

(58) **Field of Classification Search**

CPC G06F 9/5005; G06F 9/5066; G06F 15/17381
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,264,840 A * 11/1993 Wells et al. 345/599
5,903,888 A * 5/1999 Cohen et al.

(Continued)

FOREIGN PATENT DOCUMENTS

JP H06-089262 A 3/1994
JP 09-198358 A 7/1997

(Continued)

OTHER PUBLICATIONS

Aridor, Y., Domany, T., Goldshmidt, O, Shmueli, E., Morera, J., and Stockmeyer, L. 2004. "Multi-Toroidal Interconnects: Using Additional Communication Links to Improve Utilization of Parallel Computers". In Pro. 10th Workshop on Job Scheduling SAtrategies for Parallel Processing, New York.*

J. P. Hayes and T. Mudge, "Hypercube supercomputers," Prm. IEEE, v. 77, Dec. 1989, pp. 1829-1841.*

(Continued)

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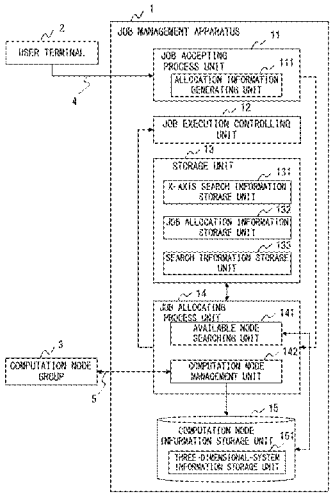
Assistant Examiner — Jacob Dascomb
(74) *Attorney, Agent, or Firm* — Fujitsu Patent Center

(57) **ABSTRACT**

A job management apparatus that searches for an available node to which a job is allocatable in an n-dimensional mesh-connected or n-dimensional torus-connected computer network, includes: a one-dimensional search information generating unit that generates one-dimensional search information related to one dimension of n dimensions, which includes a plurality of bits and which indicates, using one-bit information, whether or not the job is allocatable for each of computation nodes belonging to the one dimension; a search information generating unit that generates a search mask pattern with as many bits as corresponds to the plurality of bits, which includes consecutive bits being set to a preset value and corresponding to a size required by the job in the one dimension; and an available node searching unit that searches for the available node by performing, for the one dimension, a preset logic operation with the one-dimensional search information and the search mask pattern.

6 Claims, 16 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

8,429,664	B2 *	4/2013	Ajima et al.	718/104
2005/0235286	A1 *	10/2005	Ballew et al.	718/100
2006/0101104	A1	5/2006	Bhanot et al.	

FOREIGN PATENT DOCUMENTS

JP	2005-310139	A	11/2005
JP	2007-206986		8/2007
JP	2007-206987	A	8/2007
JP	2008-516346	A	5/2008

OTHER PUBLICATIONS

H. Y. Youn, H. Choo. and S.M. Yoo, "Dynamic task scheduling and allocation for 3D torus multicomputer systems." Int'l Conf. on Parallel Processing. III-199-206, Aug. 1996.*

Notification of Transmittal of Translation of The International Preliminary Report on Patentability (Form PCT/IB/338, Form PCT/IB/373 & Form PCT/ISA/237), International Application No. PCT/JP2010/063534, 6 pages, dated Mar. 21, 2013.

International Search Report, mailed in connection with PCT/JP2010/063534 and mailed Nov. 16, 2010.

* cited by examiner

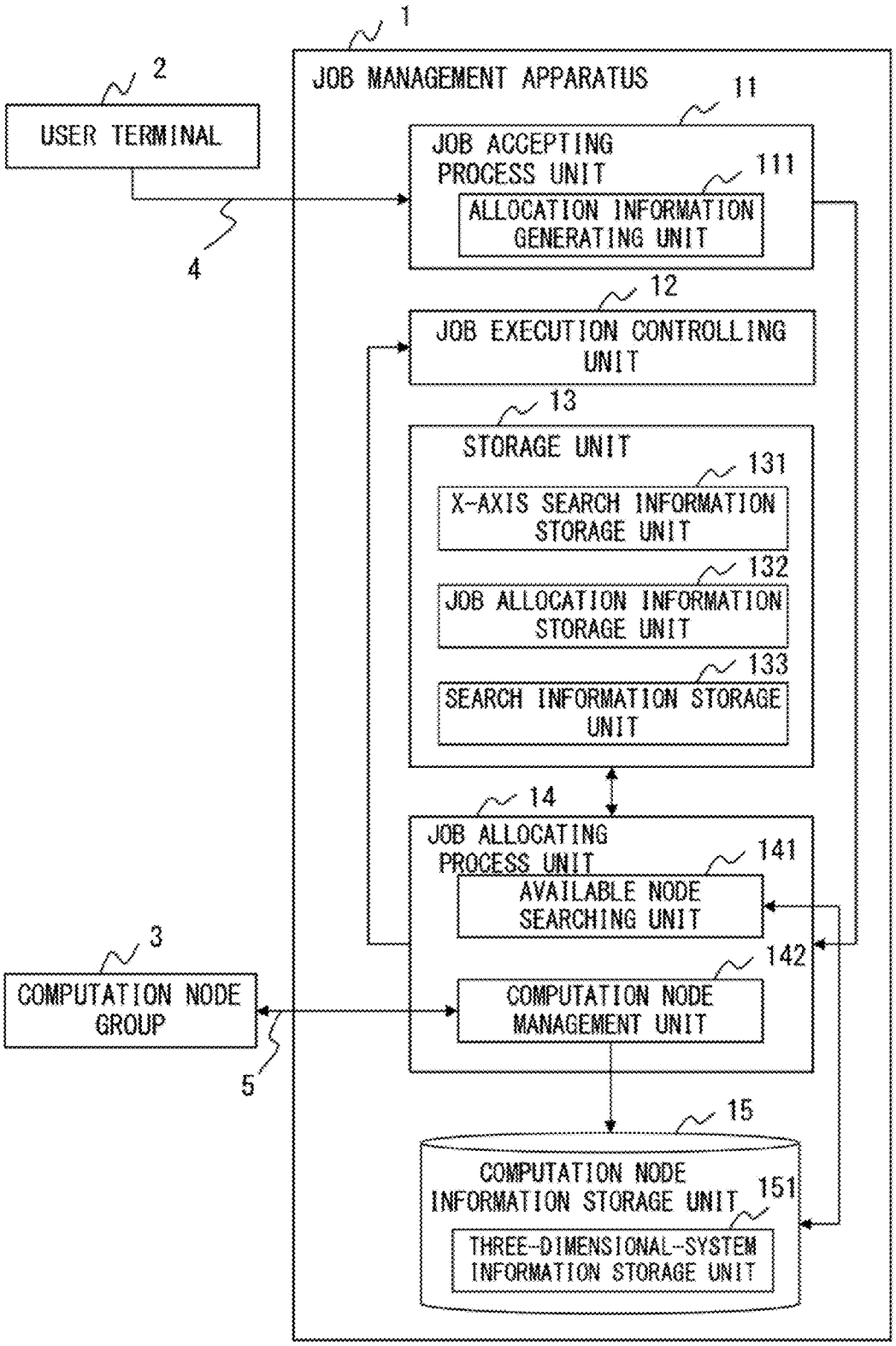

1
JOB MANAGEMENT APPARATUS
2
USER TERMINAL
4
11
JOB ACCEPTING PROCESS UNIT
111
ALLOCATION INFORMATION GENERATING UNIT
12
JOB EXECUTION CONTROLLING UNIT
13
STORAGE UNIT
131
X-AXIS SEARCH INFORMATION STORAGE UNIT
132
JOB ALLOCATION INFORMATION STORAGE UNIT
133
SEARCH INFORMATION STORAGE UNIT
14
JOB ALLOCATING PROCESS UNIT
141
AVAILABLE NODE SEARCHING UNIT
142
COMPUTATION NODE MANAGEMENT UNIT
3
COMPUTATION NODE GROUP
5
15
COMPUTATION NODE INFORMATION STORAGE UNIT
151
THREE-DIMENSIONAL-SYSTEM INFORMATION STORAGE UNIT

FIG. 1

FIG. 2A

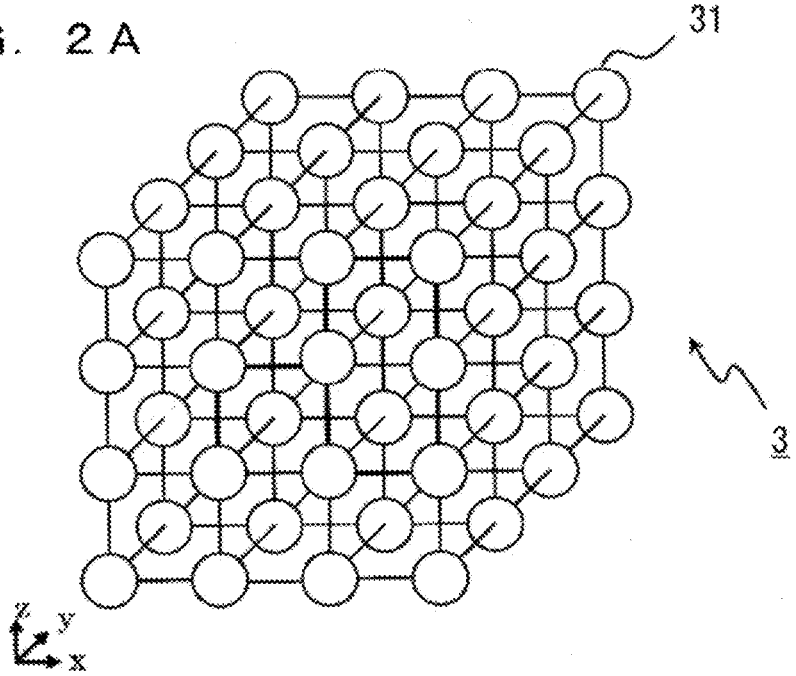


FIG. 2B

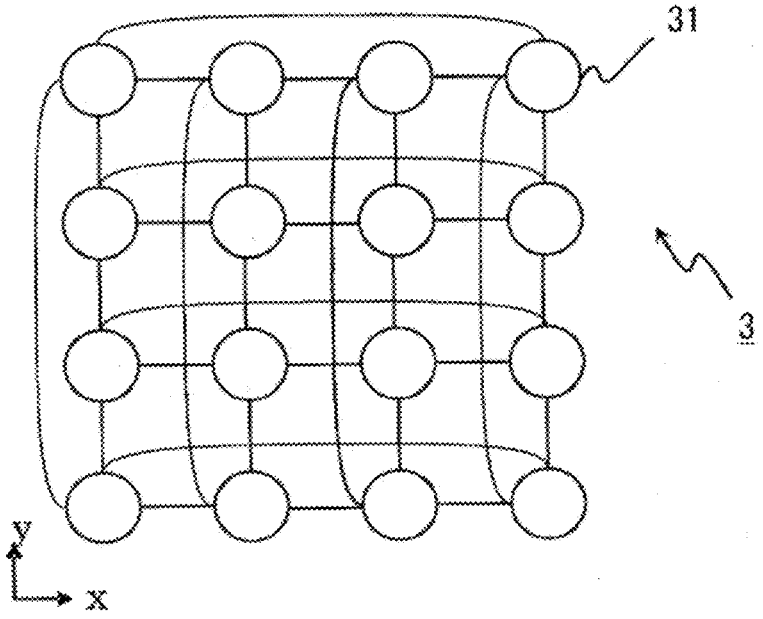


FIG. 3A

151'

```
unsigned long nobes[systemX][systemY][systemZ];
```

FIG. 3B

131'

```
unsigned long nobes_x[systemY][systemZ];
```

FIG. 3C

132'

```
struct job_info{
        unsigned long position_x; //JOB START COORDINATE(x)
        unsigned long position_y; //JOB START COORDINATE(y)
        unsigned long position_z; //JOB START COORDINATE(z)
        unsigned long shape_x;    //JOB SHAPE(x)
        unsigned long shape_y;    //JOB SHAPE(y)
        unsigned long shape_z;    //JOB SHAPE(z)
        bool     flag;            //ALLOCATABLE FLAG
}
```

FIG. 3D

133'

```
struct search_info{
        unsigned long position_x; //JOB START COORDINATE(x)
        unsigned long position_y; //JOB START COORDINATE(y)
        unsigned long position_z; //JOB START COORDINATE(z)
        unsigned long shape_x;    //JOB SHAPE(x)
        unsigned long shape_y;    //JOB SHAPE(y)
        unsigned long shape_z;    //JOB SHAPE(z)
        unsigned long mask;       //SEARCH MASK PATTERN
        int      shift_all;       //TOTAL NUMBER OF SHIFTS
        int      shift;           //NUMBER OF SHIFTS
}
```

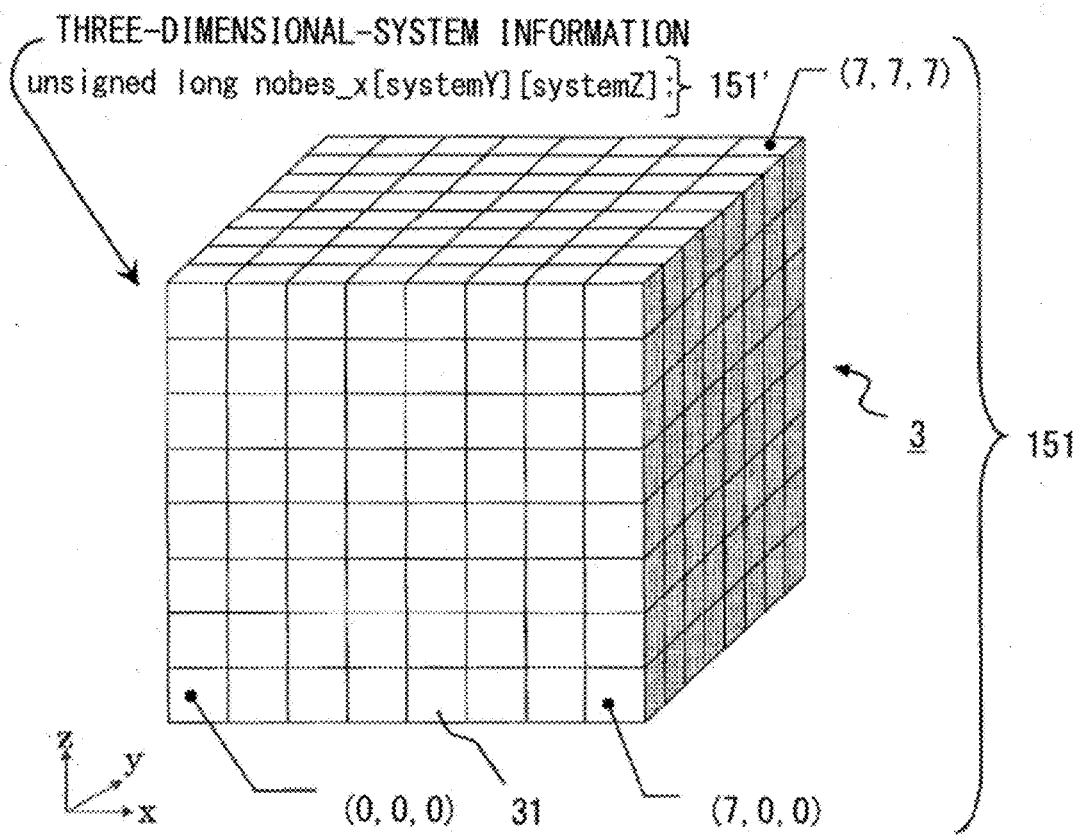

THREE-DIMENSIONAL-SYSTEM INFORMATION
unsigned long nobes_x[systemY][systemZ];
151'
(7, 7, 7)
3
151
z
y
x
(0, 0, 0)
31
(7, 0, 0)

FIG. 4

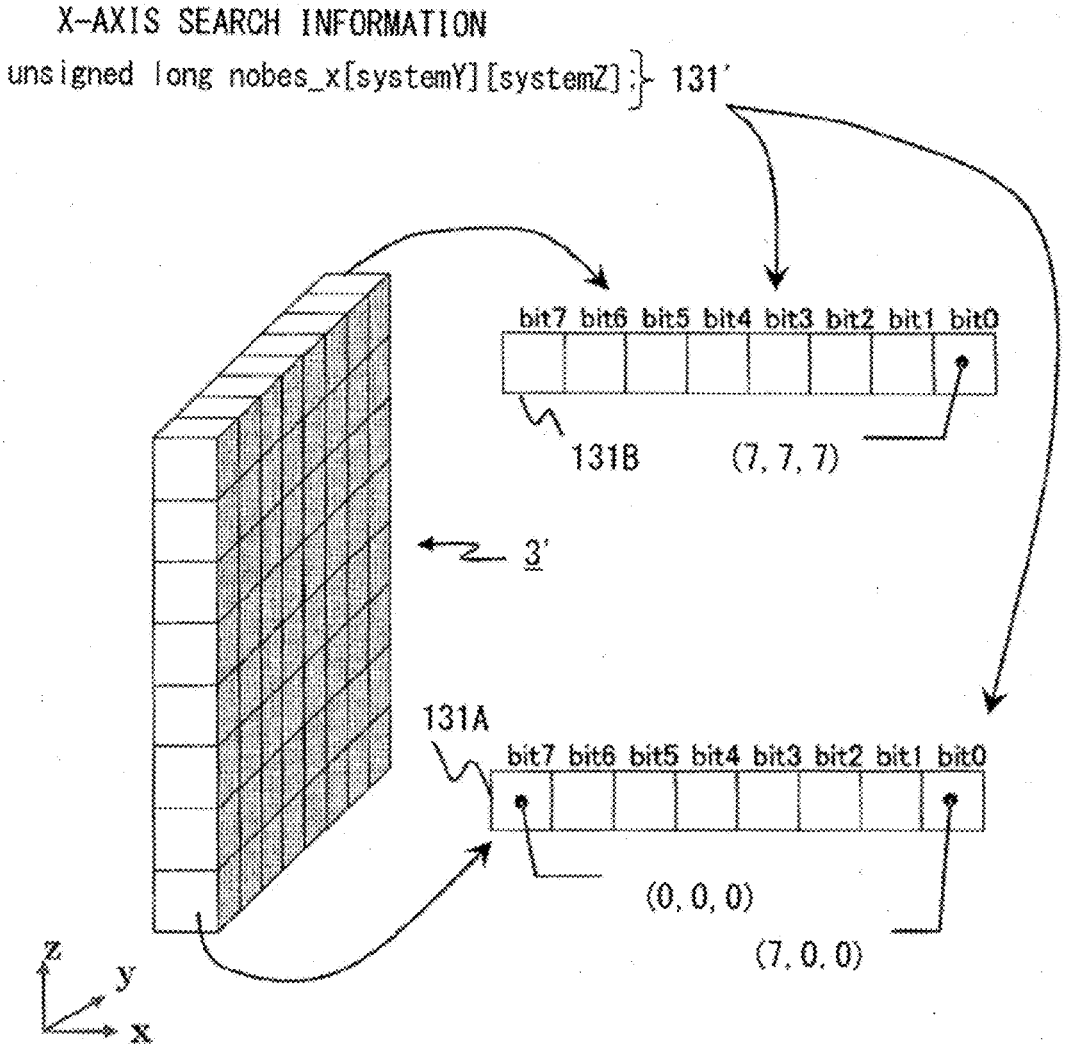

X-AXIS SEARCH INFORMATION
unsigned long nobes_x[systemY][systemZ]
131'
bit7 bit6 bit5 bit4 bit3 bit2 bit1 bit0
131B
(7, 7, 7)
3'
131A
bit7 bit6 bit5 bit4 bit3 bit2 bit1 bit0
(0, 0, 0)
(7, 0, 0)
z
y
x

FIG. 5

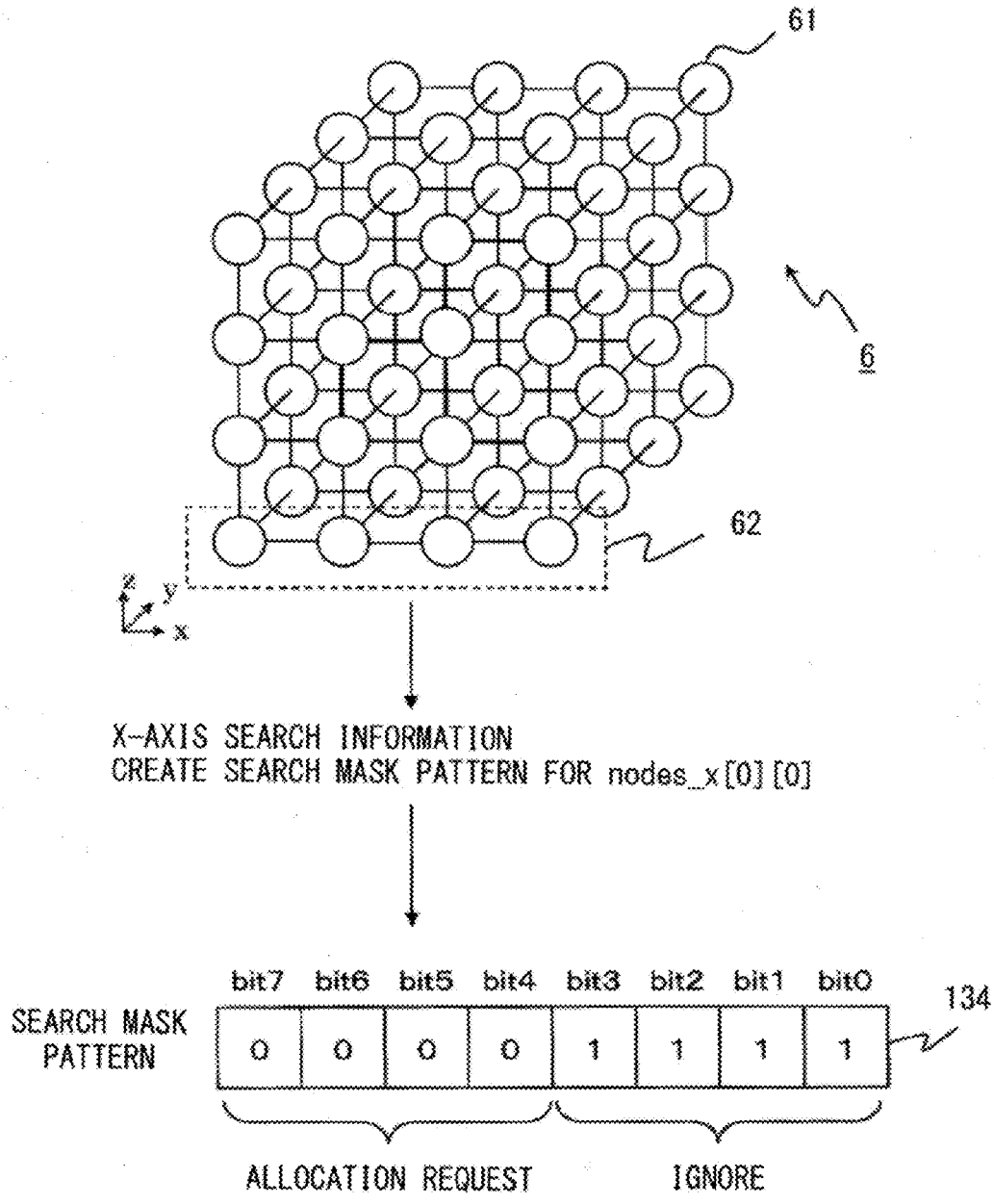

61
6
62
z
y
x
X-AXIS SEARCH INFORMATION
CREATE SEARCH MASK PATTERN FOR nodes_x[0][0]
bit7 bit6 bit5 bit4 bit3 bit2 bit1 bit0
SEARCH MASK PATTERN
0 0 0 0 1 1 1 1
134
ALLOCATION REQUEST
IGNORE

FIG. 6

X-AXIS SEARCH INFORMATION		SEARCH MASK PATTERN		DETERMINATION RESULT	
STATUS	BIT VALUE	STATUS	BIT VALUE	STATUS	BIT VALUE
IN USE	0	IGNORE	1	ALLOCATABLE	1
IN USE	0	ALLOCATION REQUEST	0	UNALLOCATABLE	0
AVAILABLE	1	IGNORE	1	ALLOCATABLE	1
AVAILABLE	1	ALLOCATION REQUEST	0	ALLOCATABLE	1

FIG. 7

FIG. 8A

X-AXIS SEARCH INFORMATION

bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
0	0	0	1	1	1	0	0

131C

FIG. 8B

SEARCH MASK PATTERN

bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
0	0	0	1	1	1	1	1

134B

FIG. 8C

RESULT OF OR OPERATION

bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
0	0	0	1	1	1	1	1

FIG. 8D

SEARCH MASK PATTERN

bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
1	0	0	0	1	1	1	1

134C

FIG. 8E

RESULT OF OR OPERATION

bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
1	0	0	1	1	1	1	1

FIG. 9A

SEARCH MASK PATTERN

bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
1	1	0	0	0	1	1	1

134D

FIG. 9B

RESULT OF OR OPERATION

bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
1	1	0	1	1	1	1	1

FIG. 9C

SEARCH MASK PATTERN

bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
1	1	1	0	0	0	1	1

134E

FIG. 9D

RESULT OF OR OPERATION

bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
1	1	1	1	1	1	1	1

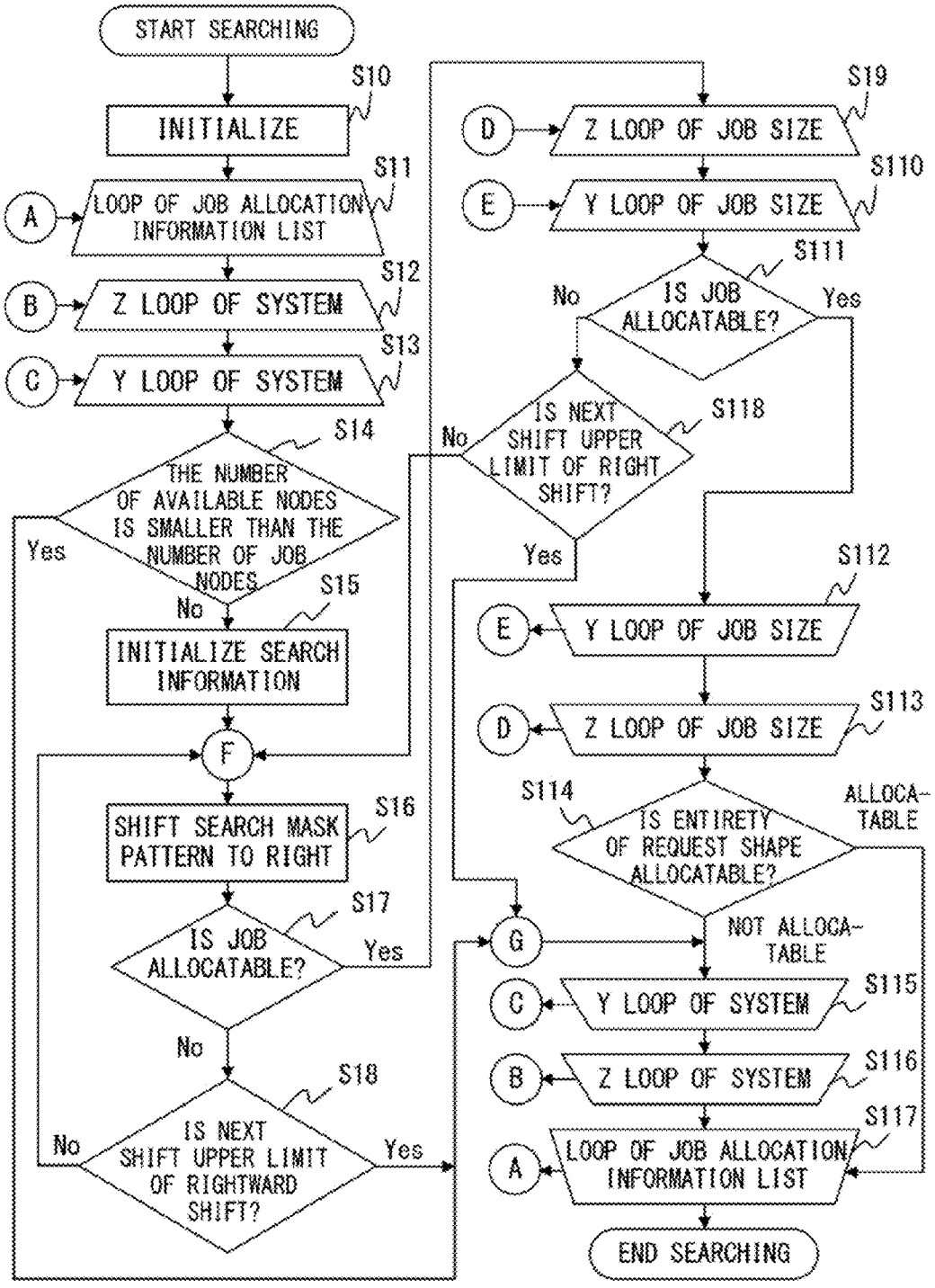

START SEARCHING
S10
INITIALIZE
S11
A
LOOP OF JOB ALLOCATION INFORMATION LIST
S12
B
Z LOOP OF SYSTEM
S13
C
Y LOOP OF SYSTEM
S14
THE NUMBER OF AVAILABLE NODES IS SMALLER THAN THE NUMBER OF JOB NODES
Yes
No
S15
INITIALIZE SEARCH INFORMATION
F
S16
SHIFT SEARCH MASK PATTERN TO RIGHT
S17
IS JOB ALLOCATABLE?
Yes
No
S18
IS NEXT SHIFT UPPER LIMIT OF RIGHTWARD SHIFT?
No
Yes
S19
D
Z LOOP OF JOB SIZE
S110
E
Y LOOP OF JOB SIZE
S111
IS JOB ALLOCATABLE?
No
Yes
S118
IS NEXT SHIFT UPPER LIMIT OF RIGHT SHIFT?
No
Yes
S112
E
Y LOOP OF JOB SIZE
S113
D
Z LOOP OF JOB SIZE
S114
IS ENTIRETY OF REQUEST SHAPE ALLOCATABLE?
ALLOCATABLE
NOT ALLOCATABLE
G
S115
C
Y LOOP OF SYSTEM
S116
B
Z LOOP OF SYSTEM
S117
A
LOOP OF JOB ALLOCATION INFORMATION LIST
END SEARCHING

FIG. 10

EXAMPLE OF FIG. 16		EXAMPLE OF FIG. 10	
LOOP TYPE	MAXIMUM NUMBER OF LOOPS	LOOP TYPE	MAXIMUM NUMBER OF LOOPS
Z LOOP OF SYSTEM	systemZ-jobZ+1	Z LOOP OF SYSTEM	systemZ-jobZ+1
Y LOOP OF SYSTEM	systemY-jobY+1	Y LOOP OF SYSTEM	systemY-jobY+1
X LOOP OF SYSTEM	systemX-jobX+1	X LOOP OF SYSTEM	1
Z LOOP OF JOB SIZE	jobZ	Z LOOP OF JOB SIZE	jobZ
Y LOOP OF JOB SIZE	jobY	Y LOOP OF JOB SIZE	jobY
X LOOP OF JOB SIZE	jobX	X LOOP OF JOB SIZE	1

FIG. 11

FIG. 12A

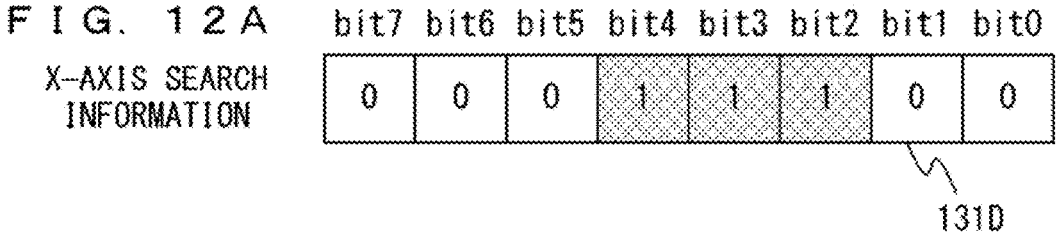


FIG. 12B

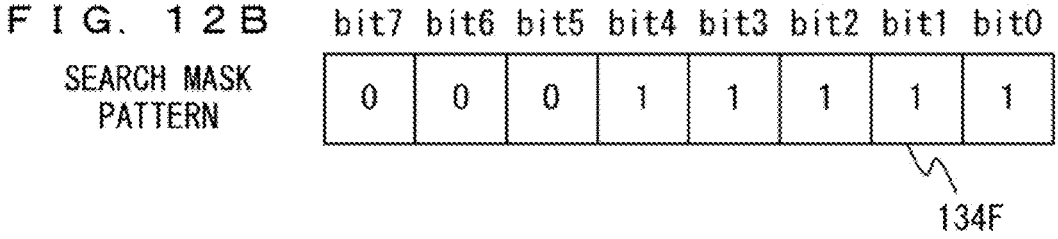


FIG. 12C

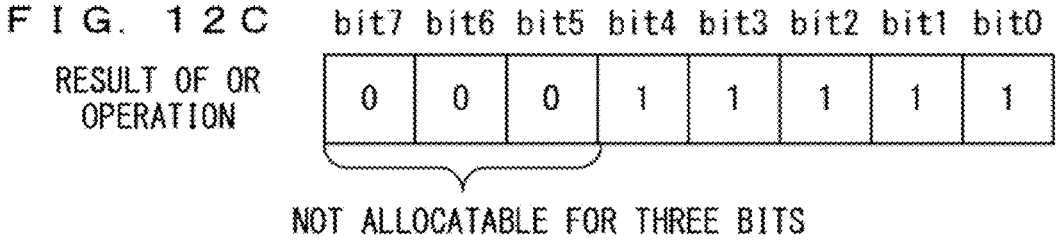


FIG. 12D

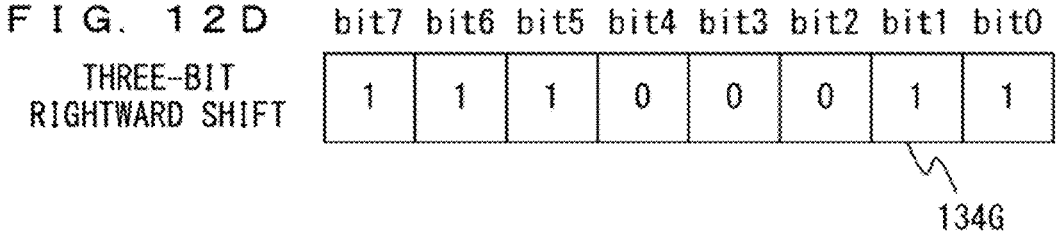


FIG. 12E

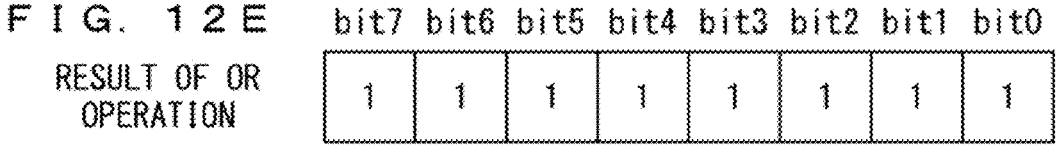


FIG. 13A

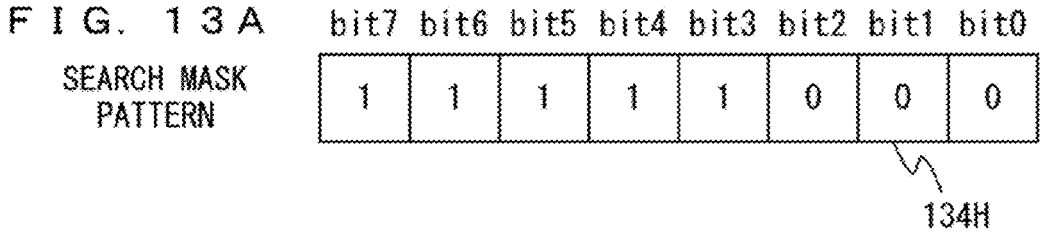
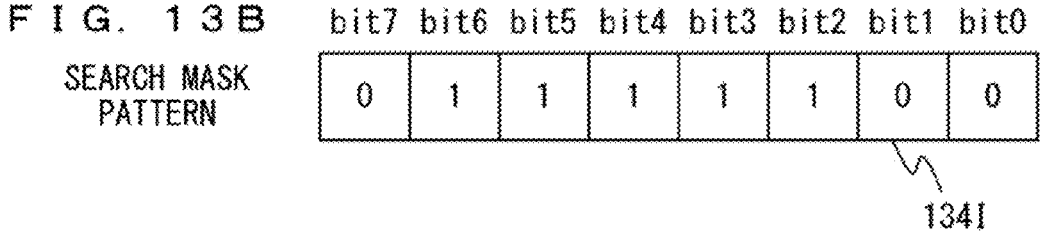


FIG. 13B



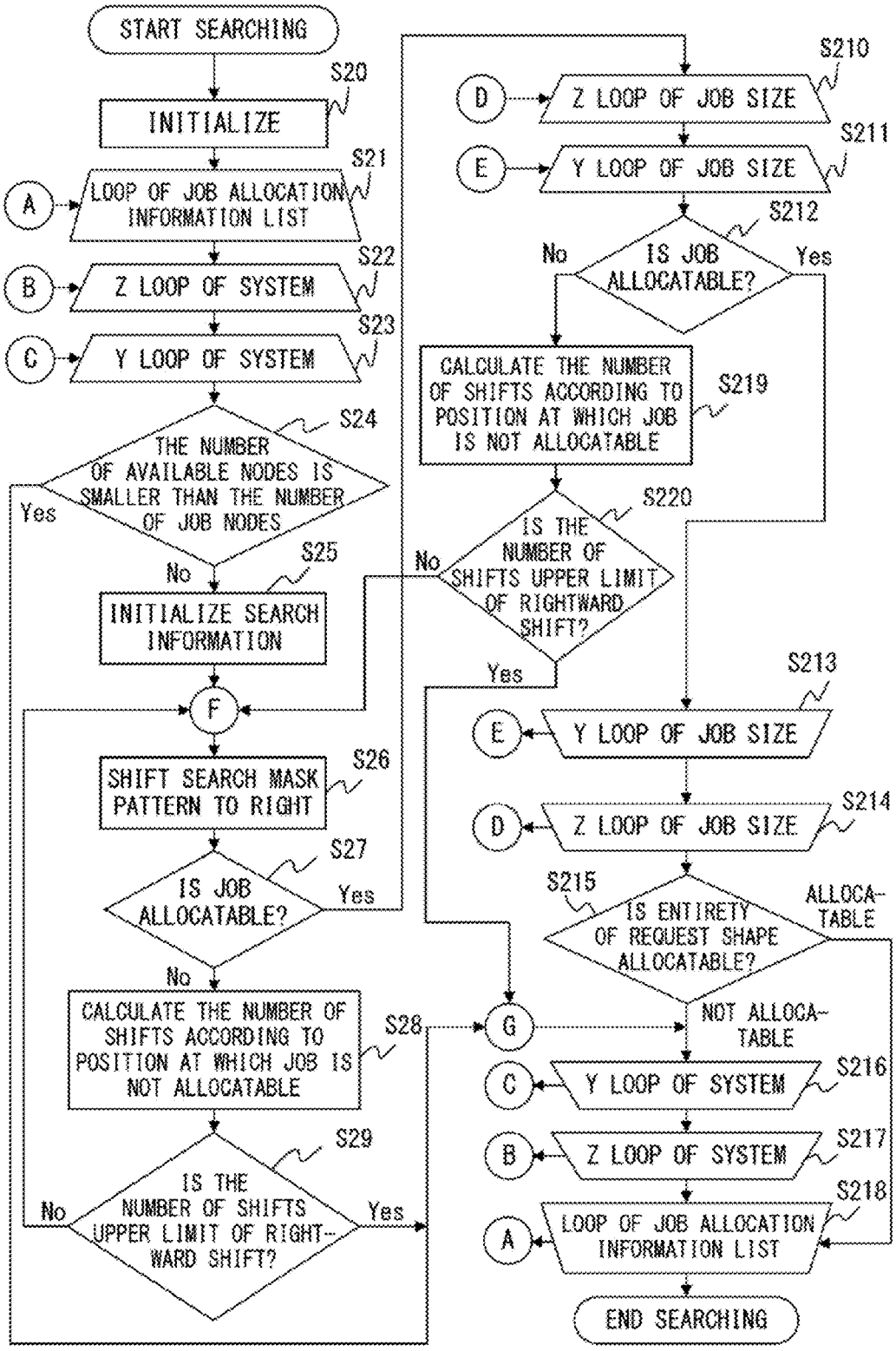

START SEARCHING
S20
INITIALIZE
S21
A
LOOP OF JOB ALLOCATION INFORMATION LIST
S22
B
Z LOOP OF SYSTEM
S23
C
Y LOOP OF SYSTEM
S24
THE NUMBER OF AVAILABLE NODES IS SMALLER THAN THE NUMBER OF JOB NODES
Yes
No
S25
INITIALIZE SEARCH INFORMATION
F
S26
SHIFT SEARCH MASK PATTERN TO RIGHT
S27
IS JOB ALLOCATABLE?
Yes
No
S28
CALCULATE THE NUMBER OF SHIFTS ACCORDING TO POSITION AT WHICH JOB IS NOT ALLOCATABLE
S29
IS THE NUMBER OF SHIFTS UPPER LIMIT OF RIGHTWARD SHIFT?
No
Yes
S210
D
Z LOOP OF JOB SIZE
S211
E
Y LOOP OF JOB SIZE
S212
IS JOB ALLOCATABLE?
No
Yes
S219
CALCULATE THE NUMBER OF SHIFTS ACCORDING TO POSITION AT WHICH JOB IS NOT ALLOCATABLE
S220
IS THE NUMBER OF SHIFTS UPPER LIMIT OF RIGHTWARD SHIFT?
No
Yes
S213
E
Y LOOP OF JOB SIZE
S214
D
Z LOOP OF JOB SIZE
S215
IS ENTIRETY OF REQUEST SHAPE ALLOCATABLE?
ALLOCATABLE
NOT ALLOCATABLE
G
C
Y LOOP OF SYSTEM
S216
B
Z LOOP OF SYSTEM
S217
A
LOOP OF JOB ALLOCATION INFORMATION LIST
S218
END SEARCHING

FIG. 14

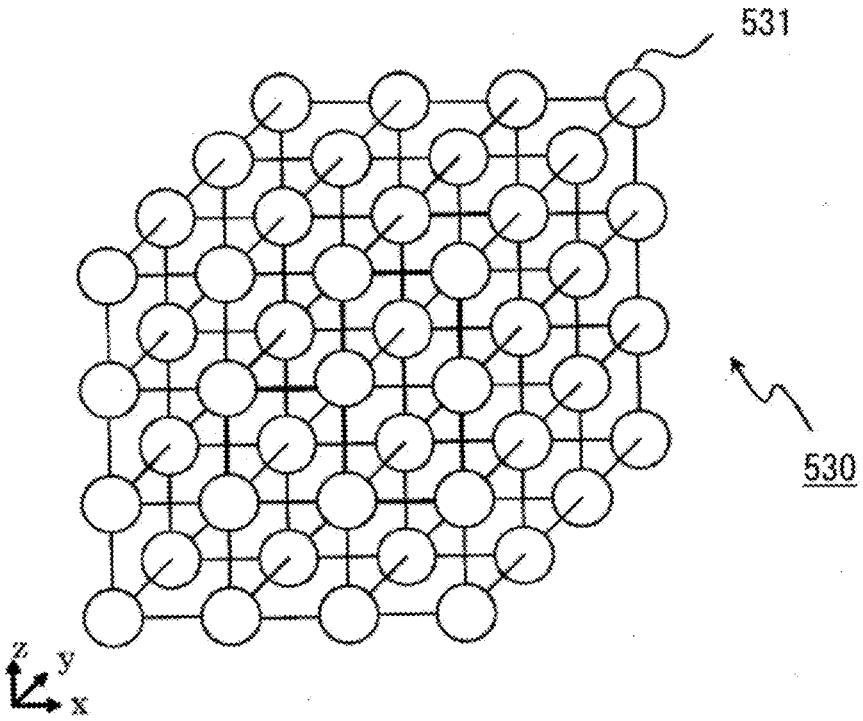


FIG. 15

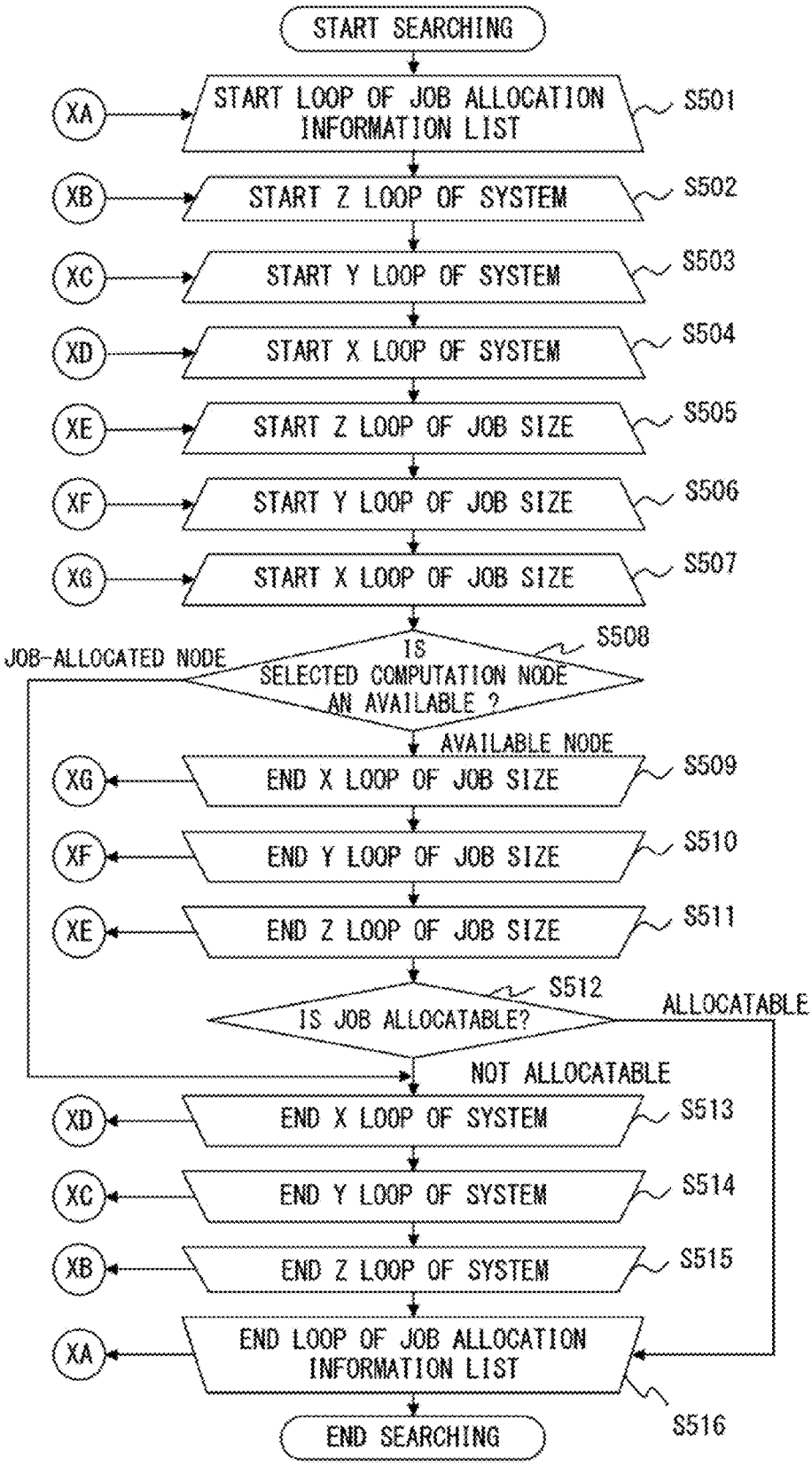

START SEARCHING
XA
START LOOP OF JOB ALLOCATION INFORMATION LIST
S501
XB
START Z LOOP OF SYSTEM
S502
XC
START Y LOOP OF SYSTEM
S503
XD
START X LOOP OF SYSTEM
S504
XE
START Z LOOP OF JOB SIZE
S505
XF
START Y LOOP OF JOB SIZE
S506
XG
START X LOOP OF JOB SIZE
S507
IS SELECTED COMPUTATION NODE AN AVAILABLE ?
S508
JOB-ALLOCATED NODE
AVAILABLE NODE
XG
END X LOOP OF JOB SIZE
S509
XF
END Y LOOP OF JOB SIZE
S510
XE
END Z LOOP OF JOB SIZE
S511
IS JOB ALLOCATABLE?
S512
ALLOCATABLE
NOT ALLOCATABLE
XD
END X LOOP OF SYSTEM
S513
XC
END Y LOOP OF SYSTEM
S514
XB
END Z LOOP OF SYSTEM
S515
XA
END LOOP OF JOB ALLOCATION INFORMATION LIST
S516
END SEARCHING

FIG. 16

JOB MANAGEMENT APPARATUS AND JOB MANAGEMENT METHOD

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation application of International Application PCT/JP2010/063534, filed on Aug. 10, 2010 and designated the U.S., the entire contents of which are incorporated herein by reference.

FIELD

The embodiments described herein are related to a job management apparatus and a job management method.

BACKGROUND

In a parallel computer network, which is a computer system that performs parallel processes, a plurality of computers which form a computation node group are connected via a network. Complete connections, Fat-Tree connections, mesh connections, torus connections, and so on are known as connection forms of computation nodes achieved by a network. The mesh connection and the torus connection from among these forms connect proximate nodes to each other so that more than several thousand computation nodes can be connected at a low cost. Accordingly, in parallel computer systems that include more than several thousand computation nodes, a two-dimensional torus connection and a three-dimensional mesh connection are often used.

A grid computer system has been proposed in which a super scheduler of a master node has a function of generating a grid model composed of logical nodes according to the connection topology of the plurality of nodes and inter-node connecting devices of the grid computer system, a function of analyzing a service request comprising a plurality of tasks supplied to the grid computer system, a function of determining the number of child nodes serving as base points for securing nodes needed for each service request in the grid model according to an analysis result of the service request, and a function of decentralizing and arranging the determined number of child nodes in the grid model.

As another example, a technology has been proposed wherein a disk is effectively utilized by providing within a memory a free record control area in which a take-over information file is managed, and an operating condition is expressed by one bit, i.e., expressed as "1" when each record of the file uses the control area and is expressed as "0" when each record of the file does not use the control area.

PRIOR ART DOCUMENTS

Patent Documents

Patent document 1: Japanese Laid-open Patent Publication No. 2007-206986

Patent document 2: Japanese Laid-open Patent Publication No. 6-089262

SUMMARY

According to an aspect of the embodiments, a job management apparatus searches for an available node which is a computation node in an n-dimensional in is an integer that is two or higher) mesh-connected or n-dimensional torus-connected computer network and to which a job is allocatable. The job management apparatus includes; a one-dimensional search information generating unit configured to generate one-dimensional search information, which is search information related to one dimension of n dimensions, which includes a plurality of bits, and which indicates, using one-bit information, whether or not the job is allocatable for each of a plurality of computation nodes belonging to the one dimension of the n dimensions; a search information generating unit configured to generate a search mask pattern with as many bits as corresponds to the plurality of bits, the search mask pattern including consecutive bits that correspond to a size required by the job in relation to the one dimension of the n dimensions and that are set to a preset value; and an available node searching unit configured to search for the available node by performing, for the one dimension of the n dimensions, a preset logic operation with the one-dimensional search information and the search mask pattern.

The object and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are not restrictive of the invention.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** illustrates a configuration of a job management apparatus;

FIGS. **2**A-**2**B illustrate a configuration of a job management apparatus;

FIGS. **3**A-**3**D are an explanatory diagram of a job management process;

FIG. **4** illustrates an example of a job management process;

FIG. **5** illustrates an example of a job management process;

FIG. **6** illustrates an example of a job management process;

FIG. **7** illustrates an example of a job management process;

FIGS. **8**A-**8**E illustrate an example of a job management process;

FIGS. **9**A-**9**D illustrate an example of a job management process;

FIG. **10** illustrates a flow of a job management process;

FIG. **11** is an explanatory diagram of a job management process;

FIGS. **12**A-**12**E illustrate another example of a job management process;

FIGS. **13**A-**13**B illustrate yet another example of a job management process;

FIG. **14** illustrates a flow of another job management process;

FIG. **15** is an explanatory diagram of an analyzed job management process of the present invention; and

FIG. **16** illustrates a flow of an analyzed job management process of the present invention.

DESCRIPTION OF EMBODIMENTS

In parallel computer systems, job execution times of a plurality of computers which form a computation node group are roughly classified into actual computation times of computation nodes and times of communication between the computation nodes. Thus, an increase in the time of communication between computation nodes is a cause of an increase in the job execution time.

Accordingly, in a mesh-connected or torus-connected parallel computer system, a broadband communication channel is provided between adjacent nodes, and a plurality of unit jobs are allocated to a computation node group having a consecutive rectangular or cuboid shape. A unit job is a divi-

sion of one job entered by a user. A job execution time may be prevented from increasing by allocating a plurality of unit jobs to the computation node group having a consecutive rectangular or cuboid shape.

A job management apparatus performs an allocating process of allocating a plurality of unit jobs to the computation node group having a consecutive rectangular or cuboid shape. The job management apparatus searches for and allocates an available node to the unit job. The available node is a computation node to which a new unit job is allocatable. When it takes a long time to search for an available node, a time required to wait for job execution appears long to users. Moreover, when it takes a long time to search for an available node, the rate of operation of the parallel computer system is decreased.

Accordingly, the inventor analyzed a process of searching for an available node in a parallel computer system.

A job entered by a user is accepted by the job management apparatus and is divided into a plurality of unit jobs. The plurality of unit jobs are allocated to and executed by a computation node executed by the job management apparatus. To allocate a job to a computation node, the job allocation apparatus searches for an available node.

As an example, assume that a computation node group **530** is connected by a three-dimensional mesh network as illustrated in FIG. **15**. In this case, the job management apparatus performs a process of searching for an available node **531** as illustrated in FIG. **16**.

The job management apparatus starts a loop of a job allocation information list (step S**501**). In particular, the job management apparatus selects one job allocation information list in accordance with a preset order.

Subsequently, the job management apparatus starts a job defined by the selected job allocation information list, i.e., a sixfold loop process to allocate a computation job.

First, the job management apparatus starts a z-direction loop of the computation node group **530**, i.e., a z-direction loop or the system (step S**502**). In particular, the job management apparatus selects a z-direction coordinate of the computation node group **530** in accordance with a preset order. The loop range of the z-direction loop of the computation node group **530** extends from "1" to "system size−job size+1".

Next, the job management apparatus starts a y-direction loop of the computation node group **530**, i.e., a y-direction loop of the system (step S**503**). In particular, the job management apparatus selects a y-direction coordinate of the computation node group **530** in accordance with a preset order. The loop range of the y-direction loop of the computation node group **530** extends from "1" to "system size−job size+1".

Subsequently, the job management apparatus starts an x-direction loop of the computation node group **530**, i.e., an x-direction loop of the system (step S**503**). In particular, the job management apparatus selects an x-direction coordinate of the computation node group **530** in accordance with a preset order. The loop range of the x-direction loop of the computation node group **530** extends from "1" to "system size−job size+1".

Through steps S**502** to S**504**, a start point of job allocating in the computation node group **530**, i.e., a start node **531**, is selected.

Next, the job management apparatus starts a z-direction loop of a job size in the job allocation information list selected in step S**501** (step S**505**). In particular, the job management apparatus selects a z-direction position of the job size in the job allocation information list in accordance with a preset order. The loop range of the z-direction loop of the job size extends from "1" to "job size".

The job management apparatus then starts a y-direction loop of the job size in the job allocation information list (step S**506**). In particular, the job management apparatus selects a y-direction position of the job size in the job allocation information list in accordance with a preset order. The loop range of the y-direction loop of the job size extends from "1" to "(job size)".

The job management apparatus then starts an x-direction loop of the job size in the job allocation information list (step S**507**). In particular, the job management apparatus selects an x-direction position of the job size in the job allocation information list in accordance with a preset order. The loop range of the x-direction loop of the job size extends from "1" to "(job size)".

Through steps S**505** to S**507**, a computation node **531** that corresponds to a certain position in the job allocation information list is selected with reference to the aforementioned start point.

Next, the job management apparatus determines whether or not the selected computation node **531** is an available node (step S**508**). When the selected computation node **531** is not an available node, i.e., when the selected computation node **531** is a job-allocated node, the job management apparatus performs step S**513** without performing steps S**509** to S**512**.

When the selected computation node **531** is an available node, the job management apparatus ends the x-direction loop of the job size in the job allocation information list (step S**509**). In particular, the job management apparatus repeats step S**507** when the execution of the aforementioned loop range for the x direction of the job size has not been ended, and the job management apparatus performs step S**510** when the execution of the aforementioned loop range for the x direction of the job size has been ended.

Next, the job management apparatus ends the y-direction loop of the job size, in the job allocation information list (step S**510**). In particular, the job management apparatus repeats step S**506** when the execution of the aforementioned loop range for the y direction of the job size has not been ended, and the job management apparatus performs step S**511** when the execution of the aforementioned loop range for the y direction of the job size has been ended.

Subsequently, the job management apparatus ends the z-direction loop of the job size in the job allocation information list (step S**511**). In particular, the job management apparatus repeats step S**505** when the execution of the aforementioned loop range for the z direction of the job size has not been ended, and the job management apparatus performs step S**512** when the execution of the aforementioned loop range for the z direction of the job size has been ended.

The job management apparatus then determines whether or not the job is allocatable to the computation node group **530** in view of a result of the aforementioned processes (step S**512**). When the job is allocatable to the computation node group **530**, the job management apparatus performs step S**516**. When the job is not allocatable to the computation node group **530**, the job management apparatus performs step S**513**.

Next, the job management apparatus ends the x-direction loop of the computation node group **530** (step S**513**). In particular, the job management apparatus repeats step S**504** when the execution of the aforementioned loop range for the x direction of the computation node group **530** has not been ended. The job management apparatus performs step S**514**

when the execution of the aforementioned loop range for the x direction of the computation node group **530** has been ended.

Subsequently, the job management apparatus ends the y-direction loop of the computation node group **530** (step S**514**). In particular, the job management apparatus repeats step S**503** when the execution of the aforementioned loop range for the y direction of the computation node group **530** has not been ended. The job management apparatus performs step S**515** when the execution of the aforementioned loop range for the y direction of the computation node group **530** has been ended.

The job management apparatus then ends the z-direction loop of the computation node group **530** (step S**515**). In particular, the job management apparatus repeats step S**502** when the execution of the aforementioned loop range for the z direction of the computation node group **530** has not been ended. The job management apparatus performs step S**516** when the execution of the aforementioned loop range for the z direction of the computation node group **530** has been ended.

Next, the job management apparatus ends the loop of the job allocation information list (step S**516**). In particular, the job management apparatus checks whether or not the current job allocation information list is the final list; when the current job allocation information list is not the final list, the job management apparatus repeats step S**501**, and, when the current job allocation information list is the final list, the job management apparatus ends the process.

In view of the descriptions above, in order to define a job start point, a triple loop consisting of the z-direction loop, the y-direction loop, and the x-direction loop of the computation node group **530** needs to be executed. Thus, a total sixfold loop needs to be executed. To allocate a job in a consecutive cuboid shape, a triple loop consisting of the z-direction loop, the y-direction loop, and the x-direction loop of the job size in a job allocation information list needs to be executed. As a result, a job is allocated to the computation node group **530** by executing a sixfold loop.

Accordingly, as the size of the computation node group **530** increases, the processing time of a sixfold loop required to search for an available node increases. This extends a time required to wait for execution of an entered job and decreases the rate of operation of the computation node group **530**.

In accordance with a disclosed job management apparatus and a disclosed job management method, available nodes that are computation nodes which form a consecutive rectangular or cuboid shape and to which a plurality of unit jobs are allocated are efficiently searched for in a computer system that performs parallel processes.

First Embodiment

FIG. **1** and FIGS. **2**A-**2**B illustrate a configuration of a job management apparatus. FIGS. **3**A-**3**D are an explanatory diagram of a job management process.

As illustrated in FIG. **1**, a parallel computer system includes a job management apparatus **1**, a user terminal **2**, and a computation node group **3**. The job management apparatus **1** is connected to the user terminal **2** via a first network **4** and to the computation node group **3** via a second network **5**. The first network **4** and the second network **5** may be the same network.

The computation node group **3** includes a plurality of computation nodes **31** connected as illustrated in FIG. **2**A. The computation node group **3** illustrated in FIG. **2**A is a three-dimensionally mesh-connected computer network, i.e., a three-dimensional mesh network. Thus, in the example in FIG. **1**, the computation node group **3** is a three-dimensional mesh network. In the three-dimensional mesh network, only adjacent-computation nodes **31** are connected.

As illustrated in FIG. **2**B, the computation node group **3** may be a two-dimensionally torus-connected computer network, i.e., a two-dimensional torus network. Also in the two-dimensional torus network, only adjacent computation nodes **31** are connected. The computation nodes **31** at both ends may be considered to be adjacent. The computation node group **3** may be an n-dimensional computer network. Note that n is an integer that is two or greater.

The job management apparatus **1** searches for an available node **31** and allocates a job to a computation node **31** according to a result of the searching. A computation node **31** within the computation node group **3** to which a job is allocatable will hereinafter be referred to as an available node **31**. Accordingly, the job management apparatus **1** includes a job accepting process unit **11**, a job execution controlling unit **12**, a storage unit **13**, a job allocating process unit **14**, and a computation node information storage unit **15**. The job accepting process unit **11** includes an allocation information generating unit **111**. The storage unit **13** includes an x-axis search information storage unit **131**, a job allocation information storage unit **132**, and a search information storage unit **133**. The job allocating process unit **14** includes an available node searching unit **141** and a computation node management unit **142**. The computation node information storage unit **15** includes a three-dimensional-system information storage unit **151**.

The storage unit **13** is a memory used by the job accepting process unit **11**, the job execution controlling unit **12**, and the job allocating process unit **14**. The computation node information storage unit **15** is a memory used by the computation node management, unit **142**. The job accepting process unit **11**, the job execution controlling unit **12**, and the job allocating process unit **14** are implemented by a process program.

The computation node management unit **142** generates three-dimensional-system information **151'** for the computation node group **3**. As an example, the computation node management unit **142** generates the three-dimensional-system information **151'** illustrated in FIG. **3**A according to structure information and availability information. The structure information and the availability information are input to the computation node management unit **142** and held in the information storage unit **15**. The generated three-dimensional-system information **151'** is stored in the three-dimensional-system information storage unit **151** of the computation node information storage unit **15**. Three-dimensional-system information **151'** will be described hereinafter.

Structure information indicates the position of each computation node **31** of the computation node group **3**. Availability information indicates whether each computation node **31** is "available" or is "in use". A position in the computation node group **3** is expressed by an x coordinate which indicates an x-direction position of the computation node group **3**, a y coordinate which indicates a y-direction position, and a z coordinate which indicates a z-direction position. In three-dimensional-system information, an available node is indicated as logic "1" and an in-use node is indicated as logic "0".

The job accepting process unit **11** receives and executes a job entering command transmitted from the user terminal **2**. In other words, the job accepting process unit **11** accepts and transmits the received job entering command to the job allocating process unit **14**.

Meanwhile, the allocation information generating unit **111** of the job accepting process unit **11** generates the job alloca-

tion information **132'** illustrated in FIG. **3**C according to the job entering command and transmits this job allocation information **132'** to the job allocating process unit **14**. The job allocation information **132'** at this moment only stores an initial value, as will be described hereinafter. The job allocating process unit **14** stores the received job allocation information **132'** in the job allocation information storage unit **132** of the storage unit **13**. The job allocation information **132'** will be described hereinafter.

The available node searching unit **141** of the job allocating process unit **14** allocates a job to the computation node group **3**. In particular, according to the three-dimensional-system information **151'**, the available node searching unit **141** generates x-axis search information **131'**, illustrated in FIG. **3**B. The generated x-axis search information **131'** is stored in the x-axis search information storage unit **131** of the storage unit **13**. The x-axis search information **131'** will be described hereinafter.

According to job allocation information **132'**, the available node searching unit **141** generates search information **133'**, illustrated in FIG. **3**D. The generated search information **133'** is stored in the search information storage unit **133** of the storage unit **13**. The job allocation information **132'** will be described hereinafter.

The search information **133'** includes a search mask pattern, as will be described hereinafter. The search mask pattern is used to search for an available node **31**.

Using the x-axis search information **131'** and the search information **133'**, the available node searching unit **141** searches for an available node **31** in the computation node group **3**. In this case, the available node searching unit **141** actually searches for an available node **31** mainly by performing a logic operation with the x-axis search information **131'** and the search mask pattern. The available node searching unit **141** allocates a job to an available node **31** according to a result of the searching for the available node **31**. In other words, the available node searching unit **141** completes and transmits the job allocation information **132'** to the job execution controlling unit **12**.

The job execution controlling unit **12** controls execution of the job according to the received job allocation information **132'**. In other words, the job execution controlling unit **12** causes the computation node **31** to which the job has been allocated to execute the job.

In the following, a job allocating process in a parallel computer system will be specifically described with reference to FIG. **4** to FIGS. **9**A-**9**D.

FIG. **4** illustrates an example of three-dimensional-system information.

As illustrated in FIG. **4**, the computation node management unit **142** generates three-dimensional-system information **151'** for each computation node **31** of the computation node group **3**. The three-dimensional-system information **151'** is actually a three-dimensional array representation of the structure of the computation node group **3**.

In the three-dimensional-system information **151'** in FIG. **3**A, [systemX] is a value within the range of the x direction of the computation node group **3**, [systemY] is a value within the range of the y direction of the computation node group **3**, and [systemZ] is a value within the range of the z direction of the computation node group **3**. Accordingly, according to structure information, the computation node management unit **142** defines as [systemX] a minimum value to a maximum value of the x coordinates of the plurality of computation nodes **31**, defines as [systemY] a minimum value to a maximum value of the y coordinates of the plurality of computation nodes **31**, and defines as [systemZ] a minimum value to a maximum value of the z coordinates of the plurality of computation nodes **31**. As a result, as illustrated in FIG. **4**, the computation node group **3** may be represented as a cuboid shape.

As an example, in FIG. **4**, the x coordinates go from 0 to 7, the y coordinates go from 0 to 7, and the z coordinates go from 0 to 7. Thus, the maximum value of [systemX] is 8, the maximum value of [systemY] is 8, and the maximum value of [systemZ] is 8. In this case, the configuration of the computation node group **3** is 8×8×8. The ranges of [systemX], [systemY], and [systemZ] may be different from each other.

Meanwhile, three-dimensional-system information **151'** includes available node information for each computation node **31** included in the computation node group **3**. The available node information indicates logic "1" to indicate that the computation node **31** is an available node or indicates logic "0" to indicate that the computation node **31** is an in-use node.

FIG. **5** illustrates an example of x-axis search information.

As illustrated in FIG. **5**, the available node searching unit **141** generates x-axis search information **131'** according to three-dimensional-system information **151'**. The x-axis search information **131'** is the search information related to one of three dimensions. In other words, x-axis search information **131'** is one-dimensional search information. The one-dimensional search information includes a plurality of bits. Using one-bit information, the x-axis search information **131'** indicates whether or not a job is allocatable for each of the plurality of computation nodes belonging to the x axis, which is one of the three dimensions. In other words, the x-axis search information **131'** represents, with one bit, each of a plurality of elements of an array x of the three-dimensional-system information **151'** and stores the plurality of elements of the array x with one variable.

Instead of x-axis search information **131'**, y-axis search information or z-axis search information may be generated.

In the x-axis search information **131'** in FIG. **3**B, x is all of the values in the x direction of the computation node group **3**. Meanwhile, [systemY] is a value within the range of the y direction of the computation node group **3**, and [systemZ] is a value within the range of the z direction of the computation node group **3**. Accordingly, the x-axis search information **131'** includes a plurality of pieces of x-axis search information, namely, x-axis search information **131**A, **131**B, and so on. In other words, the x-axis search information **131'** is generated for each of the computation nodes **31** which have common coordinates (y, z) but each of which has a different x coordinate. The number of pieces of the x-axis search information **131'** is [systemY]×[systemZ].

As an example, x-axis search information **131**A is information related to the computation nodes **31** that have common coordinates (y, z)=(0,0). As illustrated in FIG. **5**, the x-axis search information **131**A includes the available node information related to a plurality of computation nodes **31** extending from the coordinates (x, y, z)=(0,0,0) to the coordinates (x,y,z)=(7,0,0). When, for example, the computation node **31** with the coordinates (0,0,0) is an available node, bit**7** of the x-axis search information **131**A is "1". Bit**6** to bit**0** are also determined in accordance with available node information. The number of bits of the x-axis search information **131**A is identical with [systemX], i.e., with the range of the x direction of the computation node group **3**; in the case of FIG. **5**, the number of bits is 8.

Using the x-axis search information **131'**, the computation node group **3** is indicated as a computation node group **3'** illustrated in FIG. **5**. The computation node group **3'** is obtained by replacing the three-dimensional computation node group **3** with a two-dimensional array arranged in the y

direction and the z direction, wherein, each element of the two-dimensional array is an eight-bit data row.

FIG. **6** illustrates an example of a search mask pattern.

As illustrated in FIG. **6**, the available node searching unit **141** generates a search mask pattern **134**. The search mask pattern **134** includes as many bits as corresponds to a plurality of bits of x-axis search information **131**A. In other words, the number of bits of the search mask pattern **134** is the same as the number of bits of the x-axis search, information **131**A. The search mask pattern **134** is obtained by setting, to a preset value, consecutive bits corresponding to a size which a job requests for one of the three dimensions. In other words, the search mask pattern **134** is generated for the same coordinate axis as the x-axis search information **131**A. Thus, the search mask pattern **134** in FIG. **6** is used to perform an x-axis search.

When y-axis search information or z-axis search information is generated instead of x-axis search information **131'**, a mask pattern directed to a y-axis search or a mask pattern directed to a z-axis search is generated instead of the search mask pattern **134**.

As described above, the search mask pattern **134** is included in search information **133'**, and the search information **133'** is generated according to job allocation information **132'**. Accordingly, firstly, the job allocation information **132'** in FIG. **3**C will be described.

In the job allocation information **132'** in FIG. **3**C, a job start coordinate (x) is the minimum value of [systemX] in FIG. **3**A, a job start coordinate (y) is the minimum value of [systemY] in FIG. **3**A, and a job start coordinate (z) is the minimum value of [systemZ] in FIG. **3**A. The minimum value of [systemX], the minimum value of [systemY], and the minimum value of [systems] are "0", in other words, job allocation is determined sequentially starting from the computation node **31** that has the coordinates (0,0,0).

In the job allocation information **132'** in FIG. **3**C, a job shape (x) is an x-direction size of a job, a job shape (y) is a y-direction size of the job, and a job shape (z) is a z-direction size of the job. The job shape (x), the job shape (y), and the job shape (z) are designated by a job entering command input from the user terminal **2**.

An entire request shape **6** of the job is determined according to the job shape (x), the job shape (y), and the job shape (z). As an example, when the job shape (x) is "4", the job shape (y) is "4", and the job shape (z) is "4", the entire request shape **6** of the job is determined as illustrated in FIG. **6**. In this case, assuming that the entire request shape **6** of the job is indicated as "job shape (x)×job shape (y)×job shape (z)", the entire request shape **6** of the job is "4×4×4". In other words, the entire request shape **6** of the job includes job request elements **61** of "4×4×4". Each job request element **61** corresponds to and is allocated to each computation node **31**.

In the job allocation information **132'** in FIG. **3**C, an allocatable flag is "1" when the job is allocatable to the computation node group **3** and is "0" when the job is not allocatable. At this moment, the allocatable flag is "0" since it is unclear whether or not the job is allocatable.

Assume that the number of the computation nodes **31** requested by a job, i.e., the number of unit jobs into which the job is divided, is, for example, "64". In this case, there may be a plurality of combinations of the entire shapes **6** of the job that satisfy "64". In particular, the entire request shape **6** of the job may be any of "4×4×4", "2×8×4", and "2×2×16".

Accordingly, the allocation information generating unit **111** actually generates a plurality of job allocation information lists as job allocation information **132'**. The number of the generated job allocation information lists is the number of combinations of the entire shapes **6** of the job.

Only job shapes (x), job shapes (y), and job shapes (z) are different between the plurality of job allocation information lists. As an example, in a first job allocation information list, the job shape (x) is "4", the job shape (y) is "4", and the job shape (z) is "4"; in a second job allocation information list, the job shape (x) is "2", the job shape (y) is "8", and the job shape (z) is "4"; in a third job allocation information list, the job shape (x) is "2", the job shape (y) is "2", and the job shape (z) is "16". For each of the plurality of job allocation information lists, search information **133'** is generated, and a search is performed to determine whether or not a job is allocatable.

Next, in the search information **133'** in FIG. **3**D, a job start coordinate (x) is obtained from a job start coordinate (x) of the job allocation information **132'**, a job start coordinate (y) is obtained from a job start coordinate (y) of the job allocation information **132'**, and a job start coordinate (z) is obtained from a job start coordinate (z) of the job allocation information **132'**. The job start coordinate (y) is used as an initial value of a y-direction loop of the parallel computer system, and the job start coordinate (z) is used as an initial value of a z-direction loop of the parallel computer system.

In the search information **133'** in FIG. **3**D, a job shape (x) is obtained from a job shape (x) of the job allocation information **132'**, a job shape (y) is obtained from a job shape (y) of the job allocation information **132'**, and a job shape (z) is obtained from a job shape (z) of the job allocation information **132'**. The job shape (x), the job shape (y), and the job shape (z) are fixed.

In the search information **133'** in FIG. **3**D, a search mask pattern is obtained as the search mask pattern **134** in FIG. **6**. As described above, the number of bits of the search mask pattern **134** is the same as the number of bits of the x-axis search information **131**A. Thus, the number of bits of the search mask pattern **134** that is used to search the computation node group **3** in FIG. **4** and FIG. **5** is "8".

Meanwhile, assume that the entire request shape **6** of the job includes, for example, a job shape (x) that is "4", a job shape (y) that is "4", and a job shape (z) that is "4", as illustrated in FIG. **6**. Accordingly, as described above, the search mask pattern **134** is obtained for the x axis by setting from bit**7** to bit**4**, which are consecutive bits corresponding to the size "4" requested by the job, to a preset value "0". In this case, in the search mask pattern **134**, the four consecutive bits that start from the leading bit**7** are set to "0". As a result, consecutive available nodes **31** may be detected in the x-axis direction. Also in this case, sizes other than the size for which the job requests allocation, i.e., bit**3** to bit**0** corresponding to computation nodes **31** not included in the range of job allocation, are set to "1". The computation nodes **31** not included in the range of job allocation are within a range ignored in a job allocating process. Size "4", requested for the x axis by the job, corresponds to a partial shape **62** of the entire request shape **6** of the job.

FIG. **7** illustrates an example of an available node search.

The available node searching unit **141** searches for an available node **31** by performing, for the x axis, a preset logic operation with x-axis search information **131'** and the search mask pattern **134**. Thus, as described above, in the x-axis search information **131'**, "0" indicates an in-use node and "1" indicates an available node. In the search mask pattern **134**, "0" indicates a computation node for which allocation is requested, and "1" indicates a node not included in an allocation range.

Accordingly, when an allocation request is ignorable for an in-use computation node **31** as illustrated in FIG. **7**, i.e., when

the bit value of the search mask pattern **134** is "1" for the computation node **31** with the bit value "0", any determination may be made, so it will be determined that a job is allocatable.

Assume that "1" indicates that a job is allocatable and "0" indicates that a job is not allocatable. In this case, using an operation result "1" determined by a logical sum (an OR operation) of "0" indicative of in-use and "1" indicative of ignorance, it may be determined that a job is allocatable.

The operation to determine whether a job is allocatable is not limited to a logical sum. Accordingly, various logic operations may be used in accordance with a setting of the determination logic illustrated in FIG. **7**.

When an allocation request is made for an in-use computation node **31**, i.e., when the bit value of the search mask pattern **134** is "0" for the computation node **31** with a bit value "0", it is determined that a job is not allocatable. This indicates that it is impossible to perform typical allocating. In this case, using an operation result "0" determined by the logical sum of "0" indicative of in-use and "0" indicative of an allocation request, it may be determined that a job is not allocatable.

When an allocation request is ignorable for an available computation node **31** as illustrated in FIG. **7**, i.e., when the bit value of the search mask pattern **134** is "1" for the computation node **31** with bit value "1", any determination may be made, so it will be determined that a job is allocatable. In this case, using an operation result "1" determined by a logical sum (an OR operation) of "1" indicative of an available node and "1" indicative of ignorance, it may be determined that a job is allocatable.

When an allocation request is made for an available computation node **31**, i.e., when the bit value of the search mask pattern **134** is "0" for the computation node **31** with bit value "1", it is determined that a job is allocatable. This indicates that it is possible to perform original allocating. In this case, using an operation result "1" determined by a logical sum of "1" indicative of an available node and "0" indicative of an allocation request, it may be determined that a job is allocatable.

FIGS. **8**A-**8**E and FIGS. **9**A-**9**D illustrate an example of a determination for job allocation. For convenience in describing a shift process on the search mask pattern **134**, the example illustrated in FIGS. **8**A-**8**E and FIGS. **9**A-**9**D is different from the example illustrated in FIG. **4** to FIG. **6**.

In a situation in which the aforementioned operation result of the logical sum is "0", the available node searching unit **141** performs a shift process on the search mask pattern **134**. The situation in which the operation result of the logical sum is "0" is a situation in which the logical sum of x-axis search information **131'** and the search mask pattern **134** indicates for the x axis that a job is not allocatable. The shift process on the search mask pattern **134** is shifting, for example, bit**7** to bit**4**, which are consecutive bits corresponding to size "4" requested by a job, in a preset direction by one bit. The preset direction is a direction in which a coordinate value in the x-axis direction increases, i.e., a direction toward bit**0**.

As an example, in x-axis search information **131**C, assume that bit**7** to bit**5** are "0", bit**4** to bit**0** are "1", and bit**1** to bit**0** are "0" as illustrated in FIG. **8**A. This indicates that the computation nodes **31** that correspond to bit**7** to bit**5** are in use, the computation nodes **31** that correspond to bit**4** to forcer are available, and the computation nodes **31** that correspond to bit**1** to bit**0** are in use.

As another example, in a search mask pattern **134**B, assume that bit**7** to bit**5** are "0" and bit**4** to bit**2** are "1" as illustrated in FIG. **8**B. This indicates that the computation nodes **31** that correspond to bit**7** to bit**5** are objects of an allocation request, and the computation nodes **31** that correspond to bit**4** to bit**0** are unrelated to the allocation and are thus ignorable.

The available node searching unit **141** determines a logical sum of the x-axis search information **131**C in FIG. **8**A and the search mask pattern **134**B in FIG. **8**B. The operation result of the logical sum indicates that bit**7** to bit**5** are "0" and bit**4** to bit**0** are "1" as illustrated in FIG. **8**C. Thus, bit**7** to bit**5** need to indicate "unallocatable", and bit**4** to bit**0** need to indicate "allocatable".

As described above, the computation nodes **31** that correspond to bit**7** to bit**5** are objects of the allocation request, and the computation nodes **31** that correspond to bit**4** to bit**0** are unrelated to the allocation. As a result, a job is not allocatable to the computation nodes **31** that correspond to bit**7** to bit**5** and that are objects of the allocation request.

Accordingly, for the search mask pattern **134**B in FIG. **8**B, the available node searching unit **141** shifts the consecutive bits bit**7** to bit**5** corresponding to size "3" requested by the job in the direction of bit**0** by one bit. As a result, a search mask pattern **134**C in FIG. **8**D is obtained.

After the shift process on the search mask pattern **134**B is performed, the available node searching unit **141** again searches for an available node by determining a logical sum with x-axis search information **131'** and the shifted search mask pattern **134**C.

The operation result of the logical sum of the x-axis search information **131**C in FIG. **8**A and the shifted search mask pattern **134**C in FIG. **8**D indicates that bit**7** is "1", bit**6** to bit**5** are "0", and bit**4** to bit**0** are "1", as illustrated in FIG. **8**E. Thus, bit**7** needs to indicate "allocatable", bit**6** to bit**5** need to indicate "unallocatable", and bit**4** to bit**0** need to indicate "allocatable".

As described above, the computation nodes **31** that correspond to bit**7** to bit**5** are objects of the allocation request, and the computation nodes **31** that correspond to bit**4** to bit**0** are unrelated to the allocation. As a result, a job is not allocatable to the computation nodes **31** that correspond to bit**7** to bit**5** and that are objects of the allocation request.

Accordingly, for the search mask pattern **134**C in FIG. **8**D, the available node searching unit **141** shifts the consecutive bits bit**6** to bit**4** corresponding to size "3" requested by the job in the direction of bit**0** by one bit. As a result, a search mask pattern **134**D in FIG. **9**A is obtained.

After the shift process on the search mask pattern **134**C is performed, the available node searching unit **141** again searches for an available node by determining a logical sum with x-axis search information **131'** and the shifted search mask pattern **134**D.

The operation result of the logical sum of the x-axis search information **131**C in FIG. **8**A and the search mask pattern **134**D in FIG. **9**A indicates that bit**7** to bit**6** are "1", bit**5** is "0", and bit**4** to bit**0** are "1" as illustrated in FIG. **9**B. Thus, bit**7** to bit**6** need to indicate "allocatable", bit**5** needs to indicate "unallocatable", and bit**4** to bit**0** need to indicate "allocatable".

As described above, the computation nodes **31** that correspond to bit**7** to bit**5** are objects of the allocation request, and the computation nodes **31** that correspond to bit**4** to bit**0** are unrelated to the allocation. As a result, a job is not allocatable to the computation nodes **31** that correspond to bit**7** to bit**5** and that are objects of the allocation request.

Accordingly, for the search mask pattern **134**D in FIG. **9**A, the available node searching unit **141** shifts the consecutive bits bit**5** to bit**3** corresponding to size "3" requested by the job

in the direction of bit**0** by one bit. As a result, a search mask pattern **134**E in FIG. **9**C is obtained.

After the shift process on the search mask pattern **134**D is performed, the available node searching unit **141** again searches for an available node by determining a logical sum with x-axis search information **131'** and the shifted search mask pattern **134**E.

The operation result of the logical sum of the x-axis search information **131**C in FIG. **8**A and the search mask pattern **134**E in FIG. **9**C indicates that bit**7** to bit**0** are "1" as illustrated in FIG. **9**D. Thus, bit**7** to bit**0** need to indicate "allocatable".

As described above, the computation nodes **31** that correspond to bit**7** to bit**5** are objects of the allocation request, and the computation nodes **31** that correspond to bit**4** to bit**0** are unrelated to the allocation. As a result, a job is allocatable to the computation nodes **31** that correspond to bit**7** to bit**5** and that are objects of the allocation request.

The search information related to the x axis has been described above. For the axes other than the x axis, i.e., the y axis and the z axis, the available node searching unit **141** searches for available nodes **31** by repeating a determining process of determining whether or not a node is an available node **31** in a preset order starting from a start point.

Accordingly, a process of determining a start point of a job may be performed for only the z-direction loop and the y-direction loop of the parallel computer system, thereby omitting the x-direction loop. A process of allocating a job in a consecutive rectangular shape may be performed for only the z-direction loop and the y-direction loop of the job size, thereby omitting the x-direction loop. Thus, the job is allocated to the parallel computer system by executing a fourfold loop, not a sixfold loop. Accordingly, the time required to wait for execution of an entered job may be shortened, and the rate of operation of the parallel computer system may be enhanced.

FIG. **10** illustrates a flow of a job management process.

The available node searching unit **141** performs an initializing process to generate x-axis search information **131'** according to three-dimensional-system information **151'** (step S**10**).

Next, the available node searching unit **141** starts a loop of a job allocation information list (step S**11**). The loop of the job allocation information list is a process of performing loop control as many times as the number of a plurality of job allocation lists included in job allocation information **132'**. In particular, the available node searching unit **141** selects one job allocation information list from the job allocation **132'** in accordance with a preset order. At this moment, in the job allocation information list, which is the job allocation information **132'**, "unallocatable (false)" is set for an allocatable flag.

Subsequently, the available node searching unit **141** starts a fourfold loop process to allocate a job defined in the selected job allocation information list, i.e., a computation job.

The available node searching unit **141** first starts a z-direction loop of the computation node group **3**, i.e., the parallel computer system (step S**12**). In particular, the available node searching unit **141** selects z-direction coordinates of the computation node group **3** in accordance with a preset order. The z-direction loop of the computation node group **3** will hereinafter be referred to as a "z loop of the system". The z loop of the system controls a start point of a search in the z direction. A loop range of the z loop of the system extends from "1" to "system size−job size 1".

The available node searching unit **141** then starts a y-direction loop of the computation node group **3**, i.e., the parallel computer system (step S**13**). In particular, the available node searching unit **141** selects y-direction coordinates of the computation node group **3** in accordance with a preset order. Accordingly, one piece of x-axis search information **131'** is selected. The y-direction loop of the computation node group **3** will hereinafter be referred to as a "y loop of the system". The y loop of the system controls a start point of a search in the y direction. A loop range of the y loop of the system extends from "1" to "system size−job size+1".

Through steps S**12** to S**13**, a start point of job allocating in the computation node group **3**, i.e., the x-axis search information **131'** related to the start point, is selected.

Next, for the selected x-axis search information **131'**, the available node searching unit **141** determines whether or not the number of available nodes **31** is smaller than the number of computation nodes **31** requested by the job (step S**145**). In particular, the available node searching unit **141** counts the number of "1"s in the x-axis search information **131'** and compares the counted value with an x-direction job size. When the number of available nodes **31** is less than the job size, a searching process of searching for available nodes **31** may be prevented from being performed in vain to shorten the processing time.

When the number of available nodes **31** is smaller than the number of computation nodes **31** requested by the job (Yes in step S**14**), the available node searching unit **141** performs step S**115**.

When the number of available nodes **31** is not smaller than the number of computation nodes **31** requested by the job (No in step S**14**), the available node searching unit **141** initializes search information **133'** (step S**15**).

In particular, the available node searching unit **141** sets "0" for a job start coordinate (x), a job start coordinate (y), and a job start coordinate (z) in the search information **133'**. For the search information **133'**, the available node searching unit **141** also sets, as a job shape (x), the job shape (x) from the job allocation information **132'**, sets, as a job shape (y), the job shape (y) from the job allocation information **132'**, and sets, as a job shape (z), the job shape (z) from the job allocation information **132'**. In addition, the available node searching unit **141** generates a search mask pattern **134** in the search information **133'**. In the search mask pattern **134**, as many "0"s as the number of job shapes (x) are set for bits starting from the leftmost bit bit**7**, and "1"s are set for the remaining bits. As a result, the search mask pattern **134** illustrated in, for example, FIG. **6** is obtained. In addition, the available node searching unit **141** sets "0" for the total number of shifts and "0" for the number of shifts in the search information **133'**.

Next, for the search mask pattern **134**, the available node searching unit **141** shifts as many "0"s as the number of job shapes (x) in the direction of bit **0** as many times as the number of shifts in the search information **133'**, i.e., rightward shifts are performed (step S**16**). The shift process is not performed when the number of shifts is "0". Accordingly, when the number of shifts is an initial value, the shift process is not performed. The available node searching unit **141** adds the number of shifts to the total number of shifts in the search information **133'**.

In the case of the computation node group **3** that is the torus-connected computer network illustrated in FIG. **2**B, when the sum of the x-direction job size and the total number of shifts becomes equal to or greater than the size of the x-axis search information **131'** or the search mask pattern **134**, processes will be performed as will be described hereinafter with reference to FIGS. **13**A-**13**B.

Next, the available node searching unit **141** determines whether or not a job is allocatable by performing an OR

operation with the x-axis search information **131'** and the search mask pattern **134** (step S**17**).

When a job is not allocatable (No in step S**17**), the available node searching unit **141** adds +1 to the number of shifts and then determines whether or not a next shift for as many "0"s as the number of job shapes (x) is an upper limit of the rightward shift (step S**16**). When the next shift is the upper limit of the rightward shift (Yes in step S**18**), the available node searching unit **141** performs step S**115**. When the next shift is not the upper limit of the rightward shift (No in step S**18**), the available node searching unit **141** performs step S**16**.

In the case of the computation node group **3** with the mesh connection in FIG. **2**A, the upper limit of the rightward shift indicates a situation in which the sum of the total number of shifts and the x-direction job size, becomes equal to or greater than the size of the x-axis search information **131'** or the search mask pattern **134**. In other words, when the sum of the total number of shifts and the x-direction job size is less than the size of the x-axis search information **131'** or the search mask pattern **134**, a rightward shift is not at the upper limit.

As an example, in the search mask pattern **134** in FIG. **6**, the x-direction job size is "4", and the size of the search mask pattern **134** is "8". Thus, when the total number of shifts is equal to or smaller than "3", a rightward shift is not at the upper limit; when the total number of shifts is equal to or larger than "4", a rightward shift is at the upper limit.

In the case of the computation node group **3** with the torus connection in FIG. **2**B, when the total number of shifts is less than the size of the x-axis search information **131'** or the search mask pattern **134**, step S**16** is performed since a rightward shift is not at the upper limit. When the total number of shifts is equal to or greater than the size of the x-axis search information **131'** or the search mask pattern **134**, step S**115** is performed since a rightward shift is at the upper limit.

When a job is allocatable in step S**17** (Yes in step S**17**), the available node searching unit **141** starts a z-direction loop of a job site in the job allocation information list selected in step S**11** (step S**19**). In particular, the available node searching unit **141** selects z-direction positions of a job size in the job allocation information list in accordance with a preset order. The z-direction loop in the job allocation list will hereinafter be referred to as a "z loop of the job size". The z loop of the job size controls, in the z direction, searching for an available node performed in accordance with the search mask pattern **134**. A loop range of the z loop of the job size extends from "1" to "job size".

Next, the available node searching unit **141** starts a y-direction loop of a job size in the job allocation information list (step S**110**). In particular, the available node searching unit **141** selects y-direction positions of a job size in the job allocation information list in accordance with a preset order. The y-direction loop in the job allocation list will hereinafter be referred to as a "y loop of the job size". The y loop of the job size controls, in the y direction, searching for an available node performed in accordance with the search mask pattern **134**. A loop range of the y loop of the job size extends from "1" to "job size". Through steps S**19** to S**110**, the x-axis search information **131'** that corresponds to a certain position in the job allocation list is selected with reference to the aforementioned start point.

Next, the available node searching unit **141** determines whether or not a job is allocatable by performing an OR operation with the x-axis search information **131'** and the search mask pattern **134** (step S**111**).

When a job is not allocatable (No in step S**111**), the available node searching unit **141** adds +1 to the number of shifts and then determines whether or not a next shift for as many "0"s as the number of job shapes (x) is an upper limit of the rightward shift (step S**118**). When the next shift is the upper limit of the rightward shift (Yes in step S**118**), the available node searching unit **141** performs step S**115**. When the next shift is not the upper limit of the rightward shift (No in step S**118**), the available node searching unit **141** performs step S**16**. The description of the upper limit of the rightward shift which was given above is also true for this situation.

In step S**111**, when a job is allocatable (Yes in step S**111**), the available node searching unit **141** ends the y-direction loop of the job size in the job allocation information list (step S**112**). In particular, when the execution of the aforementioned loop range for the y direction of the job size does not end, the available node searching unit **141** repeats step S**110**, and when the execution of the aforementioned loop range for the y direction of the job size ends, the available node searching unit **141** performs step S**113**.

Next, the available node searching unit **141** ends the z-direction loop of the job size in the job allocation information list (step S**113**). In particular, when the execution of the aforementioned loop range for the a direction of the job size does not end, the available node searching unit **141** repeats step S**19**, and when the execution of the aforementioned loop range for the z direction of the job size ends, the available node searching unit **141** performs step S**114**.

Subsequently, the available node searching unit **141** determines whether or not the entirety of the request shape **6** of the job in FIG. **6** is allocatable (step S**114**). When the entirety of the request shape **6** of the job in FIG. **6** is allocatable, the available node searching unit **141** performs step S**117**.

When the entirety of the request shape **6** of the job in FIG. **6** is not allocatable, the available node searching unit **141** ends the y-direction loop of the computation node group **3** (step S**115**). In particular, when the execution of the aforementioned loop range for the y direction of the computation node group **3** does not end, the available node searching unit **141** repeats step S**13**. When the execution of the aforementioned loop range for the y direction of the computation node group **3** ends, the available node searching unit **141** performs step S**116**.

Next, the available node searching unit **141** ends the z-direction loop of the computation node group **3** (step S**116**). In particular, when the execution of the aforementioned loop range for the z direction of the computation node group **3** does not end, the available node searching unit **141** repeats step S**12**. When the execution of the aforementioned loop range for the z direction of the computation node group **3** ends, the available node searching unit **141** performs step S**117**.

Next, the available node searching unit **141** ends the loop of the job allocation information list (step S**117**). In particular, the available node searching unit **141** checks whether or not the current job allocation information list is the final list; when the current job allocation information list is not the final list, the available node searching unit **141** repeats step S**11**, and, when the current job allocation information list is the final list, the available node searching unit **141** ends the process. In this case, the available node searching unit **141** sets the job shape (x) of the search information **133'** as a shape (x) of the job allocation information of the job allocation information **132'**, sets the job shape (y) of the search information **133'** as a job shape (y) of the job allocation information of the job allocation information **132'**, and sets the job shape (z) of the search information **133'** as a shape (z) of the job allocation information of the job allocation information **132'**. The available node searching unit **141** sets "allocatable (true)" for an allocatable flag of the job allocation information **132'**.

FIG. **11** illustrates an example of an effect of decreasing of the number of loops.

In FIG. **11**, let the z-direction size of the computation node group **3** be "systemZ", let the y-direction size be "systemY", and let the x-direction size be "systemX". Moreover, let the z-direction job size be "jobZ", the y-direction job size be "jobY", and let the x-direction job size be "jobX".

In this case, according to the process illustrated in FIG. **16**, the number of z-direction loops of the computation node group **3** is "systemZ−jobZ+1", the number of y-direction loops is "systemY−jobY+1", and the number of x-direction loops is "systemX−jobX+1". Moreover, the number of z-direction loops of the job size is "jobX", the number of y-direction loops of the job size is "jobY", and the number of x-direction loops of the job size is "jobX".

By contrast, according to the process illustrated in FIG. **10**, the number of z-direction loops of the computation node group **3** is "systemZ−jobZ+1" and the number of y-direction loops is "systemY−jobY+1", but the number of x-direction loops is "1". Moreover, the number of z-direction loops of the job size is "jobZ" and the number of y-direction loops of the job size is "jobY", but the number of x-direction loops of the job size is "1".

Assume that the three-dimensional mesh connection in FIG. **2**A has a cubic shape and that the job size in FIG. **6** also has a cubic shape. In this case, since "systemZ=systemY=systemX", these values will be indicated as "system". Since "jobZ=jobY=jobX", these values will be indicated as "job". Accordingly, the number of loops may be decreased as indicated by the following formula.

$$\frac{\text{The_Example_of_FIG. 10}}{\text{The_Example_of_FIG. 16}} = \frac{(\text{job}(\text{system}-\text{job}+1))^2}{(\text{job}(\text{system}-\text{job}+1))^3} = \frac{1}{\text{job}(\text{system}-\text{job}+1)}$$

Second Embodiment

In the first embodiment, the shift process of shifting the search mask pattern **134** is performed bit by bit. Referring to FIGS. **8**A-**8**E and FIGS. **9**A-**9**D, the number of computation nodes that is smaller than the number of computation nodes **31** required by a job is the same as the number of bits of shifts that are made until an available node **31** is detected. In other words, the number of bits with operation result "0" is the same as the smallest necessary shift amount to detect an available node **31**.

Accordingly, in this example, the available node searching unit **141** calculates, for the x axis, the number of bits with operation result "0" according to an OR operation with x-axis search information **131'** and the search mask pattern **134**. The number of bits with operation result "0" is the number of bits indicating that a job is not allocatable. In addition, the available node searching unit **141** shifts consecutive bits of the search mask pattern **134** that are set as value "0" in the direction of bit**0** as many times as the number of bits with operation result "0".

As a result, the shifted search mask pattern **134** is obtained. After this, the available node searching unit **141** again searches for an available node **31** by performing an OR operation with the x-axis search information **131'** and the shifted search mask pattern **134**. Accordingly, the shift process for bits with operation result "0" is performed in one action, i.e., the number of arithmetic processes may be decreased via skipping.

FIGS. **12**A-**12**E and FIGS. **13**A-**13**B illustrate another example of a determination for job allocation.

As an example, in x-axis search information **131**D, assume that bit**7** to bit**5** are "0", bit**4** to bit**2** are "1", and bit**1** to bit**0** are "0", as illustrated in FIG. **12**A. This indicates that the computation nodes **31** that correspond to bit**7** to bit**5** are in use, the computation nodes **31** that correspond to bit**4** to bit**2** are available, and the computation nodes **31** that correspond to bit**1** to bit**0** are in use.

As another example, in a search mask pattern **134**F, assume that bit**7** to bit**5** are "0" and bit**4** to bit**0** are "1", as illustrated in FIG. **12**B. This indicates that the computation nodes **31** that correspond to bit**7** to bit**5** are objects of an allocation request, and the computation nodes **31** that correspond to bit**4** to bit**0** are unrelated to the allocation and are thus ignorable.

The available node searching unit **141** determines a logical sum of the x-axis search information **131**D in FIG. **12**A and the search mask pattern **134**F in FIG. **12**B. The operation result of the logical sum indicates that bit**7** to bit**5** are "0" and bit**4** to bit**0** are "1" as illustrated in FIG. **12**C. Thus, bit**7** to bit**5** need to be unallocatable, and bit**4** to bit**0** need to be allocatable.

As described above, the computation nodes **31** that correspond to bit**7** to bit**5** are objects of the allocation request, and the computation nodes **31** that correspond to bit**4** to bit**0** are unrelated to the allocation. As a result, a job is not allocatable to the computation nodes **31** that correspond to bit**7** to bit**5** and that are objects of the allocation request.

Accordingly, the available node searching unit **141** calculates the number of bits "0" in an operation result of a logical sum of the x-axis search information **131**D in FIG. **12**A and the search mask pattern **134**F in FIG. **12**B. The number of bits with operation result "0" is "3" as illustrated in FIG. **12**C. The number of bits with operation result "0" is the "total number of shifts". The calculated total number of shifts is set as the total number of shifts of the search information **133'** in FIG. **3**D.

The total number of shifts is calculated as follows. As an example, in an operation result of a logical sum of x-axis search information **131**D and the search mask pattern **134**F, "bit**5**" is a position at which "0" initially emerges on a path directed to the leftmost bit bit**7**. In other words, "bit**5**" is located at the rightmost position from among positions at which "0" emerges. In this case, the total number of shifts may be determined in accordance with "size of the computation node group **3**−rightmost position from among positions at which "0" emerges". Thus, since 8−5=3, the total number of shifts is "3".

According to the result of the calculation, the available node searching unit **141** shifts, in the direction of bit**0** by three bits but not by one bit, the consecutive bits bit**7** to bit**5** of the search mask pattern **134** in FIG. **12**B that correspond to size "3" requested by the job. As a result, a search mask pattern **134**G in FIG. **12**D is obtained.

After the three-bit shift process on the search mask pattern **134**F is performed, the available node searching unit **141** again searches for an available node **31** by determining a logical sum with x-axis search information **131'** and the shifted search mask pattern **134**G.

The operation result of the logical sum of the x-axis search information **131**B in FIG. **12**A and the search mask pattern **134**G in FIG. **12**D indicates that bit**7** to bit**0** are "1" as illustrated in FIG. **12**E. Thus, bit**7** to bit**0** need to indicate "allocatable".

As described above, the computation nodes **31** that correspond to bit**7** to bit**5** are objects of the allocation request, and the computation nodes **31** that correspond to bit**4** to bit**0** are unrelated to the allocation. As a result, a job is allocatable to the computation nodes **31** that correspond to bit**7** to bit**5** and that are objects of the allocation request.

Accordingly, in the process of allocating a job in a consecutive cuboid shape, the number of times the shift process on the search mask pattern **134** is performed and the number of times an OR operation is performed may be decreased. Thus, the time required to wait for execution of an entered job may be shortened, and the rate of operation of the computation node group **3** may be enhanced.

In some cases, the computation node group **3** is the torus-connected computer network illustrated in FIG. **2**B. In this case, in a search mask pattern **134**H, bit**7** to bit**3** may be "1", bit**2** to bit**0** may be "0", and the number of bits with operation result "0" may be "3" as illustrated in FIG. **13**A. In other words, the sum of the total number of shifts and the x-direction job size requested by the job may be equal to or greater than the x-axis direction size of the computation node group **3**.

In this case, the consecutive bits bit**2** to bit**0** that correspond to size "3" requested by the job are shifted by three bits in the direction of bit**0**. In this case, since bit**7** is adjacent to bit**0**, the available node searching unit **141** moves "0"s of bit**0** to bit**7** as illustrated in FIG. **13**B. As a result, bits with operation result "0" may be shifted.

Also in another embodiment, when the computation node group **3** is the torus-connected computer network illustrated in FIG. **2**B, bits with operation result "0" are shifted as illustrated in FIGS. **13**A-**13**B.

FIG. **14** illustrates a flow of another job management process.

The available node searching unit **141** basically performs processes similar to those in FIG. **10** as illustrated in FIG. **14**, but the available node searching unit **141** performs steps S**28** and S**219** in addition to the processes in FIG. **10**.

In the following, differences will be described between the processes illustrated in FIG. **14** and those illustrated in FIG. **10**.

As with steps S**10** to S**17** in FIG. **10**, the available node searching unit **141** performs steps S**20** to S**27**.

After this, when a job is not allocatable in step S**27** (No in step S**27**), the available node searching unit **141** calculates the number of shifts according to a position at which a job is not allocatable (step S**28**). In particular, the available node searching unit **141** calculates the number of bits with operation result "0".

Subsequently, according to the number of bits with operation result "0" as well as x-axis search information **131'** or the number of bits of the search mask pattern **134**, the available node searching unit **141** determines whether or not as many shifts as the number of bits with operation result "0" is an upper limit of the rightward shift (step S**29**). In other words, it is determined whether or not the consecutive bits that correspond to the size "3" requested by the job can be shifted as many times as the number of bits with operation result "0".

When as many shifts as the number of bits with operation result "0" is not the upper limit of the rightward shift (No in step S**29**), the available node searching unit **141** performs step S**26**. Accordingly, the consecutive bits that correspond to size "3" requested by the job are shifted as many times as the number of bits with operation result "0".

When as many shifts as the number of bits with operation result "0" is the upper limit of the rightward shift (Yes in step S**29**), the available node searching unit **141** performs step S**216**.

Meanwhile, when a job is allocatable in step S**27** (Yes in step S**27**), the available node searching unit **141** performs steps S**210** to S**212**.

After this, when a job is not allocatable in step S**212** (No in step S**212**), the available node searching unit **141** calculates the number of shifts according to a position at which a job is not allocatable (step S**219**). In particular, the available node searching unit **141** calculates the number of bits with operation result "0".

Subsequently, according to the number of bits with operation result "0" as well as x-axis search information **131'** or the number of bits of the search mask pattern **134**, the available node searching unit **141** determines whether or not as many shifts as the number of bits with operation result "0" is an upper limit of the rightward shift (step S**220**). In other words, it is determined whether or not the consecutive bits that correspond to size "3" requested by the job can be shifted as many times as the number of bits with operation result "0".

When as many shifts as the number of bits with operation result "0" is not the upper limit of the rightward shift (No in step S**220**), the available node searching unit **141** performs step S**26**. Accordingly, the consecutive bits that correspond to size "3" requested by the job are shifted as many times as the number of bits with operation result "0".

When as many shifts as the number of bits with operation result "0" is the upper limit of the rightward shift (Yes in step S**220**), the available node searching unit **141** performs step S**216**.

Third Embodiment

In the first and second embodiments, x-axis search information **131'** is generated, and a double loop related to the x axis is reduced. Meanwhile, when, for example, the size of the computation node group **3** is small, the number of times a shift process is performed on the search mask pattern **134** is decreased. In this case, the overhead of a generating process of generating x-axis search information **131'**, an OR operation process of computing a logical sum of the x-axis search information **131'** and the search mask pattern **134**, and a shift process on the search mask pattern **134** may become large.

In this example, accordingly, when the x-axis size of the computation node group **3**, i.e., the maximum value of [systemX], is equal to or greater than a preset first value, the available node searching unit **141** performs a shift process of shifting consecutive bits in the search mask pattern **134** according to a result of a logic operation as described above. The x-axis size of the computation node group **3** is the maximum value of [systemX]. The first value is empirically preset. When y-axis search information or z-axis search information is generated and the y-axis size or the z-axis size is equal to or greater than a preset value, a shift process of shifting consecutive bits in the search mask pattern **134** is performed according to a result of a logic operation.

Meanwhile, when the x-axis size of the computation node group **3** is less than the preset first value, the available node searching unit **141** searches for an available node **31** by further repeating, for the x axis, a determining process of determining whether or not a node is an available node **31** in a preset order starting from a start point. In other words, when the x-axis size of the computation node group **3** is less than the preset first value, the available node searching unit **141** executes the x-axis loop of the computation node group **3**.

This may prevent the overhead of the shift process on the search mask pattern **134** from being increased.

When the x-axis direction size requested by a job is equal to or greater than a preset second value, the available node searching unit **141** may shift consecutive bits in the search mask pattern **134** according to a result of a logic operation. The x-axis direction size requested by the job is the maximum value of [jobX]. The second value is empirically preset. When y-axis search information or z-axis search information is generated and the y-axis size or the z-axis size requested by the job is equal to or greater than a preset value, a shift process of shifting consecutive bits in the search mask pattern **134** may be performed according to a result of a logic operation.

When a difference between the x-axis size of the computation node group **3** and the size requested by the job is equal to or greater than a preset third value, the available node searching unit **141** may shift consecutive bits in the search mask pattern **134** according to a result of a logic operation. The third value is empirically preset. When y-axis search information or z-axis search information is generated and the difference in the y-axis direction or the difference in the z-axis direction is equal to or greater than a preset value, a shift process of shifting consecutive bits in the search mask pattern **134** may be performed according to a result of a logic operation.

Fourth Embodiment

In the first to the third embodiments, the x axis is selected as one of the three dimensions, x-axis search information **131'** is generated, and the double loop related to the x axis is reduced. Meanwhile, in the case of the computation node group **3** that has a cubic shape, applying a reduced loop to an axis direction with a greater size increases the effect of shortening a processing time that is achieved via the reduction in the loop. Also in the case of a request shape of a job that has a cubic shape, applying a reduced loop to an axis direction with a greater size increases the effect of shortening a processing time that is achieved via the reduction in the loop.

Accordingly, in this example, the computation node management unit **142** selects, as one of n dimensions, a dimension that is the longest side of the computation node group **3** in FIG. **2**A and generates search information of the selected axis. Note that the longest side is a coordinate axis having the highest value from among the maximum value of [systemX], the maximum value of [systemY], and the maximum value of [systems]. In other words, the computation node management unit **142** rotates the computation node group **3** in FIG. **2**A without changing the coordinate axes, in such a manner that the x axis becomes the dimension that is the longest side of the computation node group **3**.

Under this condition, the computation node management unit **142** allocates a job to the computation node group **3**. After this, the computation node management unit **142** rotates the computation node group **3** in FIG. **2**A backward without changing the coordinate axes, in such a manner that the dimension that is the longest side of the computation node group **3** is converted from the x axis back into the original coordinate axis. Subsequently, the job execution controlling unit **12** allocates the job to the computation node group **3** with the original coordinate axes and causes the computation node group **3** to execute the job. Accordingly, the time required to perform a job allocating process may be further shortened.

The computation node management unit **142** may select, as one of n dimensions, a dimension that is the longest side of the request shape **6** of the job in FIG. **6** and may generate search information of the selected axis. Note that the longest side is a coordinate axis having the highest value from among the maximum value of [jobX], the maximum value of [jobY], and the maximum value of [jobZ]. In other words, the computation node management unit **142** rotates the computation node group **3** in FIG. **2**A without, changing the coordinate axes, in such a manner that the x axis becomes the dimension that is the longest side of the request shape **6** of the job in FIG. **6**.

In this condition, the computation node management unit **142** allocates a job to the computation node group **3**. After this, the computation node management unit **142** rotates the computation node group **3** in FIG. **2**A backward without changing the coordinate axes, in such a manner that the dimension that is the longest side of the request shape **6** of the job in FIG. **6** is converted from the s axis back into the original coordinate axis. Subsequently, the job execution controlling unit **12** allocates the job to the computation node group **3** with the original coordinate axes and causes the computation node group **3** to execute the job. Accordingly, the time required to perform a job allocating process may be further shortened.

All examples and conditional language provided herein are intended for pedagogical purposes of aiding the reader in understanding the invention and the concepts contributed by the inventor to further the art, and are not to be construed as limitations to such specifically recited examples and conditions, nor does the organization of such examples in the specification relate to a showing of the superiority and inferiority of the invention. Although one or more embodiments of the present invention have been described in detail, it should be understood that the various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

What is claimed is:

1. A job management apparatus that searches for an available node which is a computation node in an n-dimensional mesh-connected or n-dimensional torus-connected computer network, wherein n is an integer that is two or higher, and to which a job is allocatable, the job management apparatus comprising:

a one-dimensional search information generating unit configured to generate one-dimensional search information, which is search information related to one dimension of n dimensions, which includes a plurality of bits, and which indicates, using one-bit information, whether or not the job is allocatable for each of a plurality of computation nodes belonging to the one dimension of the n dimensions;

a search information generating unit configured to generate a search mask pattern with as many bits as corresponds to the plurality of bits, the search mask pattern including consecutive bits that correspond to a size required by the job in relation to the one dimension of the n dimensions and that are set to a preset value;

an available node searching unit configured to search for the available node by performing, for the one dimension of the n dimensions, a preset logic operation with the one-dimensional search information and the search mask pattern, wherein:

when a result of the logic operation for the one dimension of the n dimensions indicates that the job is not allocatable for the one dimension of the n dimensions, the available node searching unit searches for the available node by

shifting, in a preset direction by one bit, the consecutive bits that are included in the search mask pattern and that are set to the preset value,

performing the preset logic operation with the one-dimensional search information and the shifted search mask pattern,

calculating the number of bits that indicate that the job is not allocatable according to the logic operation for the one dimension of the n dimensions,

shifting the consecutive bits that are included in the search mask pattern and that are set to the preset value in the preset direction as many times as the number of bits that indicate that the job is not allocatable, and

performing the preset logic operation with the one-dimensional search information and the shifted search mask pattern; and

an allocating unit that allocates, based on when the result of the preset logic operation indicates the job can be allocated, the job to the plurality of computation nodes.

2. The job management apparatus according to claim **1**, wherein for remaining dimensions other than the one dimension of the n dimensions, wherein the remaining dimensions are described as n−1, the available node searching unit searches for the available node by repeating a determining process of determining whether or not a node is the available node in a preset order starting from a start point.

3. The job management apparatus according to claim **1**, further comprising:

a computation node management unit configured to generate n-dimensional-system information indicating whether or not a node is the available node for each of the computation nodes in the n-dimensional mesh-connected or n-dimensional torus-connected computer network, wherein

the available node searching unit generates the one-dimensional search information according to the n-dimensional-system information.

4. The job management apparatus according to claim **1**, further comprising:

a computation node management unit configured to select, as the one dimension of the n dimensions, a dimension that is a longest side of the n-dimensional mesh-connected or n-dimensional torus-connected computer network.

5. A job management apparatus that searches for an available node which is a computation node in an n-dimensional mesh-connected or n-dimensional torus-connected computer network, wherein n is an integer that is two or higher, and to which a job is allocatable, the job management apparatus comprising:

a one-dimensional search information generating unit that generates one-dimensional search information, which is search information related to one dimension of n dimensions, which includes a plurality of bits, and which indicates, using one-bit information, whether or not the job is allocatable for each of a plurality of computation nodes belonging to the one dimension of the n dimensions;

a search information generating unit that generates a search mask pattern with as many bits as corresponds to the plurality of bits, the search mask pattern including consecutive bits that correspond to a size required by the job in relation to the one dimension of the n dimensions and that are set to a preset value;

an available node searching unit that searches for the available node by performing, for the one dimension of the n dimensions, a preset logic operation with the one-dimensional search information and the search mask pattern, wherein:

when a result of the logic operation for the one dimension of the n dimensions indicates that the job is not allocatable for the one dimension of the n dimensions, the available node searching unit searches for the available node by

shifting, in a preset direction by one bit, the consecutive bits that are included in the search mask pattern and that are set to the preset value, and

performing the preset logic operation with the one-dimensional search information and the shifted search mask pattern; and

the available node searching unit shifts the consecutive bits in the search mask pattern according to the result of the logic operation when a size of the n-dimensional mesh-connected or n-dimensional torus-connected computer network is equal to or greater than a preset first value, when a size requested by the job is equal to or greater than a preset second value, or when a difference between the size of the computer network and the size requested by the job is equal to or greater than a preset third value; and

an allocating unit that allocates, based on when the result of the preset logic operation indicates the job can be allocated, the job to the plurality of computation nodes.

6. A job management method for searching for an available node which is a computation node in an n-dimensional mesh-connected or n-dimensional torus-connected computer network, wherein n is an integer that is two or higher, and to which a job is allocatable, the job management method comprising:

generating, by a one-dimensional search information generating unit, one-dimensional search information, which is search information related to one dimension of n dimensions, which includes a plurality of bits, and which indicates, using one-bit information, whether or not the job is allocatable for each of a plurality of computation nodes belonging to the one dimension;

generating, by a search information generating unit, a search mask pattern with as many bits as corresponds to the plurality of bits, the search mask pattern including consecutive bits that correspond to a size required by the job in relation to the one dimension of the n dimensions and that are set to a preset value; and

searching for, by an available node searching unit, the available node by performing, for the one dimension of the n dimensions, a preset logic operation with the one-dimensional search information and the search mask pattern, wherein:

when a result of the logic operation for the one dimension of the n dimensions indicates that the job is not allocatable for the one dimension of the n dimensions, the available node is searched, by the available node searching unit, by

shifting, in a preset direction by one bit, the consecutive bits that are included in the search mask pattern and that are set to the preset value,

performing the preset logic operation with the one-dimensional search information and the shifted search mask pattern,

calculating the number of bits that indicate that the job is not allocatable according to the logic operation for the one dimension of the n dimensions,

shifting the consecutive bits that are included in the search mask pattern and that are set to the preset value in the preset direction as many times as the number of bits that indicate that the job is not allocatable,

performing the preset logic operation with the one-dimensional search information and the shifted search mask pattern; and

an allocating unit that allocates, based on when the result of the preset logic operation indicates the job can be allocated, the job to the plurality of computation nodes.

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